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Sulfur Oxides Pollution Control

FEDERAL RESEARCH & DEVELOPMENT PLANNING & PROGRAMMING 1968 - 1972

U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Consumer Protection and Environmental Health Service
National Air Pollution Control Administration

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PLANNING & PROGRAMMING
1968 - 1972

Issued by:

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Consumer Protection and Environmental Health Service
National Air Pollution Control Administration
Arlington, Virginia

April, 1968

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FOREWORD

Sulfur oxides are among the most common and most injurious of the pollutants that contaminate the Nation's air and threaten public health and welfare. This problem, which is already serious in many places in the country, will continue to grow and worsen unless effective control techniques are developed and applied. The task of making such techniques widely available is one which requires a concerted effort by government and industry.

For its part, the Department of Health, Education, and Welfare has underway a large-scale research and development program focused on technology for dealing with the sulfur oxides problem. Our program encompasses the combined efforts of the National Air Pollution Control Administration, several other Federal departments and agencies, and an increasing number of organizations in the private sector.

This document was prepared for use in the planning and programming of our sulfur oxides research and development effort and as an aid to coordination of the work of the various organizations involved in this effort. The funding estimates it contains do not necessarily represent the appropriations that will actually be requested--or provided--for this work. Appropriations for all of our activities are determined annually through the normal budgeting processes of the Federal Government.

This five-year plan will be updated annually to reflect the progress of research and development conducted and supported not only by the Federal Government, but also by non-governmental organizations, to the extent that such organizations make information on their work available to us. Our annual review will necessarily affect both the substance of the plan and the funding estimates.

The program outlined in this document is intended, in large measure, to stimulate and supplement research and development activities in the private sector. Those industrial firms whose operations result in discharges of sulfur oxides into the air and those research organizations whose capabilities are applicable to the development of air pollution control technology must continue to play a leading role in meeting the Nation's urgent need for practical solutions to the sulfur oxides problem.

The Federal Government's work on this problem is increasing. This growing effort is consistent with President Johnson's memorandum of April 21, 1967, to the heads of several Federal departments and agencies, and with the provisions of the Air Quality Act, which became law on November 21, 1967. But in calling for an intensified Federal effort, both the President and the Congress did so in the expectation that the efforts of industry and other private organizations would also be intensified. Our program of research and development, as it is outlined in this document, reflects that expectation.

I urge all who are concerned with the problem of sulfur oxides pollution and who are capable of helping the Nation solve this problem to participate as fully as possible in this vital part of the national effort to rid the air of its intolerable burden of pollutants.

JOHN T. MIDDLETON
Commissioner
National Air Pollution
Control Administration

PREFACE

The nationwide effort to provide techniques for sulfur oxide control has reached proportions which require an integrated and far reaching Federal plan. The Department of Health, Education, and Welfare's (HEW) National Center for Air Pollution Control (NCAPC), which has primary responsibility for the effort, undertook the development of this plan. In this undertaking, it was necessary to search out and relate the plans of other agencies whose activities have an impact on sulfur oxide control to those of NCAPC.

The Office of Program Planning and Evaluation (OPPE) of the National Center for Air Pollution Control was given the responsibility for the actual development of the integrated plan. Because of limited manpower within OPPE, a contract was negotiated with Stanford Research Institute to act as an extension of the in-house branch of OPPE in the study. The report was prepared, under the direction of Robert M. Jimeson, by personnel of the National Center for Air Pollution Control and Stanford Research Institute (SRI) whose names appear below:

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The study is presented in two parts, preceded by an Executive Digest which presents an overview. Chapter I examines the technical, social, and political factors that define the problem and provide the logic for the Federal research and development program.

Chapter II documents the present and projected Federal program. It identifies nine major component programs; these are further divided into "elements" for purposes of technical description, delineation of funding and performing responsibilities, and program phasing. This documentation results from analysis of the diverse activities of several Federal agencies; it provides uniform nomenclature wherever possible and integrates several categories of planning and programming data.

The research and development effort to implement the plan will utilize the facilities and personnel of both Federal agencies and non-Federal organizations consisting of research groups, universities, associations, and industries throughout the nation. The Federal effort will endeavor to remain cognizant of independent industry effort in sulfur oxide control and refashion the Federal program to supplement that of industry. An immediate followup effort to supplement this study will be devoted to methods for evaluating the plan in motion--for assessing the benefits of programmed work and updating the schedules of programmed events.

Much work was spent in program analysis and evaluation which is not reflected in the report, such as investigating various alternative approaches to sulfur oxide control. This work is reported separately in research memoranda from Stanford Research Institute to NCAPC entitled, "Effect of Government Patent Policies on Participation of Industry in Air Pollution Control R/D" and "Economic Aspects of Air Desulfurization and Interfuel Competition."

April 1968

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EXECUTIVE DIGEST

Introduction

The Federal Government is currently engaged in an aggressive program to develop economically acceptable methods to control emissions from important sources of atmospheric pollution. The Federally-sponsored work includes projects being conducted in Government agencies, industry, research institutes, and universities. Generally, the work is problem-oriented to the maximum, most projects being directed toward development of hardware and processes to control specific sources of pollution. Although work is going on for both vehicular and stationary sources, this report is limited to stationary sources and, more specifically, to all Federal research and development plans and programs to advance the technology for control of sulfur oxides, principally during the fiscal 68 to 72 time period.

Responsibility for Air Pollution Control

Early in 1967, the President designated responsibility to the Secretary of the Department of Health, Education, and Welfare for leadership in all aspects of air pollution control. The President emphasized the need for a greatly accelerated sulfur control program and called for participation by industry and by all available Federal laboratories.

Nature of the SO_x Pollution Problem

The quantity of the emission of sulfur oxides rates second among the pollutants discharged to the air in the United States. Sulfur oxides emission predominately comes from stationary sources. Of the total emission of sulfur oxides from stationary sources, about 46% is from power generation; 32% from industrial, commercial, and residual combustion operations; 12% from the smelting of ores; and 10% from combined industrial sources such as oil refining, coke processing, sulfuric acid manufacturing, refuse incineration, pulp and paper mills, chemical plants, and others. Thus, diverse types of sources exist, and interchange of technology may not be completely possible.

In addition, these sources include large, intermediate, and small single sources and groups of intermediate and small sources. Any of the above may be industrial, utility, government, commercial, or domestic. The multiplicity of combinations of these sources may appear in any number of topographic and meteorological regimes, further constrained by social, economic, and political considerations. Market potential of the recoverable byproducts peculiar to each of the control processes compounds even further the permutation of control devices which should be subjected to research and considered for development.

Generally, solutions which are applicable to large sources cannot justifiably be utilized for small sources. For example, stack gas scrubbing appears economically feasible when applied to large-scale combustion units, but is prohibitive in cost when similarly applied to small units and possibly even intermediate units. Furthermore, a particular stack scrubbing device may be the best economic solution for an existing combustion unit, but may be inapplicable in a congested area because of a space limitation for addition of the scrubbing unit. Further, a tall stack may be a proper solution in one topographic and meteorological regime but totally inadequate in another which has poor ventilating characteristics.

Utilization of low-sulfur fuels at a premium cost may prove to be the best solution for small sources which are densely grouped, but infeasible for large, isolated sources because of a limited supply of the fuel or its expense.

The wide variety of combustion equipment itself, whether large or small, is another factor influencing the applicability of particular control techniques. Coal is fired in a variety of methods. It can be pulverized and blown into the furnace, resulting in a high output of fly ash to be collected in the stack. The fly ash interferes with certain stack scrubbing processes, but not others. In addition, coal may be underfed with a stoker, overfired on a traveling grate, or fired to a slagging burning. In these firing methods, most of the ash is removed at the furnace bottom, thus permitting the application of those control processes which were inapplicable in pulverized firing and vice versa, negating their use in the pulverized fired units. Thus, all these examples illustrate that no single universal solution exists to the sulfur oxide control problem, but that a broad spectrum of solutions applicable to the diverse combination of factors surrounding each case is necessary.

The advent of atomic energy is expected to modify the rate of increase in unabated sulfur oxide emissions, but it is not expected to decrease the unabated quantity of SO_x emission expected in the future. Industry, with its many faceted sources of SO_x, is expected to grow, and the expanded use of atomic energy will have little impact here. In the field of power generation, total energy needs are forecast to grow faster than the growth in atomic energy capacity as predicted by the Atomic Energy Commission. The quantity of power produced by fossil fuels is expected to increase over current production. Therefore, use of atomic energy may cause dislocations in the production of power from fossil fuels, but it is not expected to affect the urgent need to control emissions from the combustion of fossil fuels nor to affect the nature of the SO_x control problem.

NCAPC Program Goals

The nature of the SO_x problem indicates that a spectrum of control devices acceptable to the wide variety of sources of SO_x emission is needed. The NCAPC research and development program for SO_x air pollution control consists, in large part, of projects that relate to some aspect of the problem of pollution from combustion sources. The work is directed toward three goals:

- Large-scale prototype and demonstration studies of processes for control of sulfur oxides from power generation. These processes include flue gas treatment, stack meteorology, fuel desulfurization and conversion, and new combustion processes. The objectives are to define control process efficiency and economies and to generate design data for full-scale equipment.

- An intensive search for new sulfur control processes having long-range potential effectiveness, greater than that of the "first-generation" processes.

- A program to develop control of sulfur emissions from sources other than combustion of fossil fuels; these sources account for roughly 30 percent of the total sulfur oxides pollution.

Other Federal agencies have goals which may provide secondary benefits for sulfur oxide pollution control. For instance, the Office of Coal Research (OCR), the Bureau of Mines (BuMines), Tennessee Valley Authority (TVA), and the Federal Power Commission (FPC) do not have a primary responsibility for air pollution control, but the results of some of their work can have an effect on SO_x emissions. Their work, in accordance with their charters, is generally resource-oriented. For example, OCR is directed by its charter to develop more efficient methods of mining, preparing, and utilizing coal. The Bureau of Mines has a responsibility to conduct work which will conserve and develop mineral resources and which will promote safe and healthful working conditions in the mineral industries. Although the goals of these agencies are primarily resource-oriented, their research, when properly oriented, contributes in a meaningful way to the control of sulfur oxides. Therefore, selected R&D efforts of these agencies are included to reflect a fully coordinated Federal plan for the control of sulfur oxides.

Approach to Developing the Federal Plan

The NCAPC-SRI study group discussed, collected, and analyzed the goals, objectives, and program plans of all Federal agencies which are conducting work with a primary or secondary impact on sulfur oxide control development. In addition, industry's independent sulfur oxide control activities, although not specifically reported, were considered in the formulation of the Federal plans. To aid in composite program analysis among agencies, the study group developed a standard format for presentation of plans and schedules. Based on the format, the plans of the agencies were integrated into a related network of R&D activities under nine major program categories. The probable time and cost schedules for achieving the events in the network, and consequently the stated goals, are shown for the integrated Federal plan. The group recognized that budgetary constraints may alter the plan. Where budgetary constraints were known, they were followed in assigning costs to projects. Where budgetary constraints were not known, the estimated cost of achieving a goal within the stated time span was specified. Each agency reviewed its program plan for accuracy in draft form.

As with any multiyear projection, the program set forth will require continuous review. It represents, nonetheless, a comprehensive plan for coordinated effort by the several Federal agencies most concerned with control of sulfur oxides pollution. It presents not only a plan for action, but also a base from which to measure progress. In it there are designated, in detail, specific programs, elements, projects, and tasks that can be readily identified and assessed.

Methodology Utilized by NCAPC to Implement Plans

The Process Control Engineering Program of the National Center for Air Pollution Control is charged with primary responsibility for management of the engineering research and development work for SO_x control. Approximately 35 technical people devote much of their time to the development and management of the research conducted under agreements with outside organizations. The intent is to utilize the expert capabilities in the Government and private sector which are readily available to work on the best ideas generated in competitive thinking. Consequently, very little funding remains in-house, only that necessary for developing and monitoring R&D agreements and for minor in-house research required for awareness and astute decision-making on the agreements.

The trend in the plans shows an increasing percentage expended on non-Federal contracts. Several factors contribute to this; e.g., the work to be undertaken involves application of skills that are neither available nor appropriate for development within Government agencies. Also, because many of the problems to be solved are understood by and are the responsibility of industry, direct involvement of industry is essential to development of effective solutions. Furthermore, the urgency of the problem dictates that expenditure be made where present competence can be found or developed rapidly in the magnitude commensurate with the scope of the problem. This generally requires maximum use of industrial groups. Finally, the nature of many projects makes it desirable to place broad responsibility in the hands of industrial groups particularly suited to undertake the work. For example, an engineering construction firm would best be employed as a prime contractor, with responsibility for design, construction, and conduct of large-scale R&D to generate data for eventual large-scale demonstrations.

In general, NCAPC strives first for the development of relatively few control methods that economically fit large classes of sulfur oxide emitters and then expands the class of emitters that can economically use a control method by adapting and improving the method or by developing new methods to apply to those classes not yet accommodated.

Program Structure

The overall Federal program for development of controls for SO_x is presented as a group of nine component programs, which are listed and defined below. The first six of these programs are directed toward developing specific solutions to control problems by experimental methods. The remaining three programs provide support for the first six.

I. Flue Gas Treatment: Development of processes for removing SO_x from the flue gases of combustion processes or from the waste gases from other processes.

II. Stack Meteorology: Studies of the behavior and dispersion of waste gases discharged from chimneys, and of the potential for mitigating the effects of SO_x emissions by discharging the waste gases through tall stacks.

III. Fuel Desulfurization: Development of processes for removing sulfur from fuels. Categories of processes: desulfurization of oil; desulfurization of coal.

IV. Fuel Conversion: Development of processes for conversion of coal to liquid, gaseous, or modified solid fuels. Opportunity for simultaneous desulfurization of the fuels is usually inherent in these processes, although desulfurization is not the primary objective. Conversion of oil to gaseous fuel is another potential category of this program but is not being actively pursued.

V. New Combustion Processes: Changes in combustion or manufacturing processes that may eliminate the release of SO_x, capture the SO_x within itself, or drastically reduce the volume of waste gas and therefore reduce the cost of subsequently collecting the SO_x.

VI. Industrial Process Control: Development of processes for the control of sulfur oxides from various industries. Work will be initiated through surveys intended to define the air pollution problem of each industry and to indicate the research and development effort required for control technology. Work will culminate in prototype control processes for each industry.

VII. Fuel Availability Surveys: Surveys of the availability and location of low-sulfur fuels, as related to regional requirements, technology, and the economic and social impacts of producing, transporting, storing, and using these fuels as an immediate sulfur oxide control measure.

VIII. Supporting Instrumentation Development: Survey of requirements for instrumentation for SO_x process control activities; determination of availability of applicable "off-the-shelf" instruments; establishment of performance specifications of new process control instrumentation; and design, development, and testing of sulfur oxide sensing and control equipment.

IX. Program Development, Analysis, and Evaluation: Development of in-house and consultant capabilities required to provide decision-supporting studies, plans, programs, and analyses; establishment of control systems for initiating and monitoring R&D programs performed in-house, by contractor, or by other Government agencies.

Each of the nine programs is composed of one or more program elements. A program element may be defined as the development of a specific process, the study of a group of processes, or the performance of a clearly definable effort or group of efforts essential to the program. Program element sheets, presented in Chapter II, contain information concerning starting and completion dates, total costs, funding organization, performing organization, project director, technical description, applicability, constraints, related R&D efforts, required tasks, schedule of their completion, source of funds, and performing organization. Tasks are definable as the steps in the development procedure which generally include some or all of the following: feasibility, laboratory, bench-scale, pilot plant, prototype plant, and demonstration plant studies.

In the real world, the actual work to achieve objectives of a program, its elements and tasks, is conducted at the project level. The project basis is used in funding research and development contracts and delineating parts of a program, program element, or task into a specific package for investigation. The scope of a project depends upon such factors as the availability of funds; the talents, objectives, and workloads of contractors and Federal agencies; the progress of collateral and interrelated projects; and the contracting policies of the agency involved. To show the relationship of individual projects to program objectives and to relate operational activities to planning, supplementary data sheets follow certain of the program element sheets in Chapter II. The project information on the supplementary data sheets consists of project identification, costs, start and completion date, executing contractors or agencies, funding source, and explanatory remarks which amplify the intent of the project or relate and integrate it into an orderly network of events.

Program Funding

As stated earlier, the agency responsible and most directly concerned with the Federal R&D control technology program for sulfur oxides is the National Center for Air Pollution Control of the Department of Health, Education, and Welfare. NCAPC plans to fund a total of $255,605,000 for projects directly oriented to control of sulfur oxides. Only a very small amount of the $255.6 million will be spent in-house. In-house spending will be for contract monitoring and for minor research needed for program awareness and guidance. Essentially, all NCAPC funds are planned to (1) support contract R&D in the private sector and (2) supply funds through transfer to other Government agencies for cooperative efforts where special capabilities are available. Table E-1 shows the distribution of the total planned funding of NCAPC by program and performing contractor or agency. The table also shows funding by fiscal year and performing group.

Of the total of $255.6 million, NCAPC plans to transfer a total of $15,251,000 to other agencies for projects which are specific and well defined at this time. The distribution of these funds among agencies and programs is shown in Table E-1. Approximately $5.5 million will be transferred to the Bureau of Mines to support bench scale and pilot plant work in alkalized alumina process development, coal washability studies, and low-sulfur coal availability surveys. A transfer of $170,000 to FPC is planned for surveys on the availability of natural gas and liquified natural gas as a low-sulfur fuel. A total of $680,000 will be transferred to TVA and ESSA field studies of plume rise and dispersion from large, tall stacks in various topographical and meteorological regimes. Also, about $8.9 million will be transferred to TVA for large-scale prototype and demonstration plant work involving selected flue gas treatment processes incorporated on certain of their power plants.

Of the total $255.6 million shown for NCAPC, approximately $60 million can be designated at this time for specific feasibility, bench scale, and pilot plant studies and for well-defined, identifiable prototype and demonstration projects to be performed in both the Government and private sectors. The distribution of these designated funds among the nine programs is shown in Table E-2.

Because of uncertainties in R&D, not every effort at this time can be specified with complete project detail, although the need for the effort and the tasks required to accomplish the objective are known. Based on past experience, cost, and time schedules can be estimated for achievement of each task. Efforts such as these are

Table E-1

TOTAL NCAPC FUNDS BY USE IN-HOUSE AND NCAPC CONTRACTOR, AND TRANSFERS TO OTHER AGENCIES

(Thousands of Dollars)

By Program

	NCAPC Funds Used	NCAPC Funds Transferred to Agencies					NCAPC
Program	In-House/Contractor	BuMines	OCR	TVA	FPC	ESSA	Total
I.	$64,278	$3,745		$8,904			$76,927
II.	1,979			260		420	2,659
III.	22,219	795					23,014
IV.	53,091						53,091
V.	22,212						22,212
VI.	65,732						65,732
VII.	3,260	957			170		4,387
VIII.	6,083						6,083
IX.	1,500						1,500
Total	$240,354	$5,497		$9,164	$170	$420	$255,605

By Fiscal Year

	NCAPC Funds Used	NCAPC Funds Transferred to Agencies					NCAPC
FY	In-House/Contractor	BuMines	OCR	TVA	FPC	ESSA	Total
Prior 68	$3,093	$1,227		$141			$4,461
68	7,309	782		1,733	20		9,844
69	35,500	1,125		4,905	50	120	41,700
70	53,502	1,059		1,875	50	150	56,636
71	64,000	719		500	50	150	65,419
72	65,400	585		10			65,995
Post 72	11,550						11,550
Total	$240,354	$5,497		$9,164	$170	$420	$255,605

Table E-2

DISTRIBUTION OF NCAPC PROGRAM FUNDS BY DESIGNATED AND UNDESIGNATED PROJECTS *

(Thousands of Dollars)

Program		NCAPC Funds for Designated Projects	NCAPC Funds for Undesignated Projects	NCAPC Total
I	Flue Gas Treatment	$38,894	$38,033	$76,927
II	Stack Meteorology	2,659	0	2,659
III	Fuel Desulfurization	5,314	17,700	23,014
IV	Fuel Conversion	1,091	52,000	53,091
V	New Combustion Processes	212	22,000	22,212
VI	Industrial Process Control	1,882	63,850	65,732
VII	Fuel Availability Surveys	2,637	1,750	4,387
VIII	Supporting Instrumentation Development	1,500	0	1,500
IX	Program Development, Analysis, and Evaluation	6,083	0	6,083
Total		$60,272	$195,333	$255,605

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* The principal time-horizon is from 1968 to 1972, although funding represents requirements for total life of projects, including expenditures made prior to FY 68 and expected beyond FY 72.

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listed as program elements with the word "undesignated" in the title of the element. The word indicates that the project details cannot be well enough defined at the present time to assign work packages and detailed funding to specific organizations. These funds are shown in Table E-2 and also incorporated in Table E-1 in the column labeled NCAPC Funds Used In-House/Contractor. At the present time, about $45 million is for specific projects which are to be performed by contractors. The balance of the funds amounting to $195,333,000 is available for project packages to be performed in either the private or Government sector, depending on comparative evaluation of proposals from all sectors. Decisions regarding allocation of the funds to specific projects among the two sectors will be based on the merits of each case, considering all the factors previously discussed as influencing the work package of a project.

Once the particulars of a project are well defined and assignable, they can be listed in detail in any future planning document. In the meantime, the projected distribution of the $195.3 million must be planned at the higher level of generality without regard to performing organization.

The $38 million for undesignated projects shown for Program I, Flue Gas Treatment, will be used to support a series of surveys covering ten areas of approach to removal of SO_2 from flue gases. The surveys will define the state of the art in each area by literature search, supplementary laboratory experimentation, preliminary conceptual design, and economic analysis, and further development to demonstration scale of those which prove worthy. The ten areas are: aqueous solutions, dry metal oxides, catalytic oxidation, inorganic liquids, organic liquids, inorganic solids other than oxides, organic solids, direct reduction to sulfur, physical methods, and fertilizer-oriented processes (TVA only).

The $17.7 million shown for future utilization in Program III, Fuel Desulfurization, will be for support of promising projects in the field of desulfurization of coal and oil on the scale required to achieve technical objectives. Emphasis will be on stimulating cooperative efforts among Government agencies and the commercial enterprises now engaged in proprietary development, with the aim of exploiting these developments for maximum application to SO_x control.

The $52 million set aside for Program IV, Fuel Conversion, has as its basis the large number of program possibilities concerned with coal gasification, liquefaction, and similar processes. NCAPC plans to conduct engineering and economic feasibility studies on the most promising for SO_x control purposes and make available a part or all of the $52 million over the program period to support the SO_x control aspects of these fuel conversion projects.

The \$22 million set aside for Program V, New Combustion Processes, has as its basis large-scale development of new combustion processes which inherently have the feature of controlling emissions of SO_x.

The \$63.8 million set aside for Program VI, Industrial Process Control, will be used to support systems studies of air pollution and control development technology from each of the various major industrial sources of SO_x emission other than utilities, e.g., non-ferrous smelting, coke manufacturing, integrated iron and steel, sulfuric acid, petroleum refining, pulp and paper, and industrial and commercial boilers. Each study will provide a comprehensive survey of the industry, the emissions it produces, process technology as related to air pollution, and the state of the art of air pollution control in the industry. The studies will lead to the funding of control development technology.

Finally, \$1.7 million has been earmarked for Program VII, Fuel Availability Surveys. This amount will be used to conduct, sponsor, or support projects for research and surveys on availability and location of low-sulfur fuels. Studies will encompass not only known conventional reserves, but also tar sands, oil shale, new gas reserves created by nuclear explosion, secondary recovery methods, and development of new low-sulfur fuels from byproducts and waste materials.

As suggested earlier, the achievement of goals and objectives of other agencies, although not directly related to air pollution, produce in some of their programs collateral benefit which have an impact on SO_x control. Table E-3 shows the distribution of funds for all programs which have an impact on SO_x control, according to funding agency and whether funds have a primary or other than primary SO_x control objective. As shown, all of NCAPC funds have as their primary objective the control of SO_x. The Bureau of Mines plans to fund a portion of the alkalized alumina development in-house in cooperation with funds received from NCAPC. In addition, that Bureau is planning to fund \$21.3 million for work resulting from the constraints of projected SO_x control requirements and having as its objective the conservation and development of the fossil fuel resource base. Because results may have an impact on SO_x control, the projects are listed in the total Federal program, although their primary objective is other than SO_x control. Most of the Bureau's projects fall in the program areas of Fuel Desulfurization, Fuel Conversion, New Combustion Processes (for high heat release), and Fuel Availability Surveys.

The \$165,135,000 planned by the Office of Coal Research is similarly oriented toward development of the resource base for coal. Successful development of the projects listed would have a collateral benefit in the control of SO_x. The projects fall in the same program areas as those of the Bureau of Mines.

The \$1.35 million planned by TVA is oriented toward producing fertilizers from the SO_x emitted in the stack gases of their power plants. These fertilizer-oriented processes will require stack scrubbing tailored specifically for the TVA system and are expected to have broader collateral benefits for SO_x control technology.

Table E-3

FUNDING SUPPORT TO R&D EFFORTS WITH IMPACT ON SO_x CONTROL *

(Thousands of Dollars)

Agency	Primary Objective SO_x Control	Charter States Primary Objective Other than SO_x Control	Total
NCAPC	$255,605	$ 0	$255,605
Bureau of Mines	474	21,296	21,770
Office of Coal Research	0	165,135	165,135
TVA	0	1,350	1,350
FPC	0	70	70
Total	$256,079	$187,851	$443,930

* Funding represents requirements for total life of projects active during the base period, including expenditures made prior to FY 68 and expected beyond FY 72.

Table E-4

RESEARCH AND DEVELOPMENT FUNDING BY AGENCY AND YEAR

(Thousands of Dollars)

Funding Agencies	Prior FY 68	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72	Total
NCAPC	$4461	$ 9844	$41700	$56636	$65419	$65995	$ 11550	$255605
Bureau of Mines	2042	1981	4009	3637	4272	3379	2450	21770
Office of Coal Research	21605	14602	42264	39873	23623	13890	9278	165135
TVA	0	150	300	300	300	300	0	1350
FPC	0	10	20	20	20	0	0	70
Total	$28108	$26587	$88293	$100466	$93634	$83564	$23278	$443930

The amounts of funds to be supplied for both direct or indirect support of efforts to control SO_x pollution and the timetable for this support are shown in Table E-4 and represent the total Federal program.

Table E-5 arrays the planned funding according to program and fiscal year and includes funds from all sources with primary and other than primary objectives with an impact on SO_x control.

Table E-5

FEDERAL SO_x CONTROL R&D PROGRAM
(Thousands of Dollars)

Program	Prior FY 68	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72	Total
I.	$ 3752	$ 7493	$ 24616	$ 22724	$12577	$ 9520	$ 0	$ 80682
II.	50	388	671	600	600	350	0	2659
III.	552	1273	5411	6847	6349	5704	7100	33236
IV.	20727	13519	46144	50353	35248	24540	1428	191959
V.	2644	1860	5835	10512	9770	10000	13700	54321
VI.	0	882	1700	6150	26000	31000	0	65732
VII.	160	612	2316	1380	1190	1050	1050	7758
VIII.	0	0	500	500	500	0	0	1500
IX.	223	560	1100	1400	1400	1400	0	6083
Total	$28108	$ 26587	$88293	$ 100466	$93634	$83564	$23278	$443930

Finally, Table E-6 summarizes the Federal program in detail. Column A shows funds used in-house and by NCAPC contractors. Funds for undesignated projects appear in this column also because the project is not yet well enough defined to be assigned for transfer to other Government agencies or to a contractor in the private sector. Until specific assignment can be made, the funds are listed as in-house. This may be misleading unless one remembers that NCAPC plans very little funding for in-house work. Column B shows the funds transfer to other agencies for specific projects. Column C indicates funds provided by other Government agencies.

Sulfur Oxide Control R&D and Related Programs

Table E-6

FUNDING SOURCES AND TRANSFERS, AND PERFORMING AGENCIES AND CONTRACTORS

(Thousands of Dollars)

Column Legend:
A-NCAPC Funds Used In-House and by NCAPC Contractor
B-NCAPC Funds Transferred to Another Agency
C-Other Agency Funds

Program Program Element Task Project (Agency or Contractor)	Prior FY 1968			FY 1968			FY 1969			FY 1970			FY 1971			FY 1972			Post FY 1972			TOTAL		
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
I. FLUE GAS TREATMENT	2367	1118	267	4692	2203	598	18239	5410	967	19625	2414	685	10905	1039	633	8450	465	605	0	0	0	64278	12649	3755
A. Alkalized Alumina Process	543	942	0	336	360	93	270	475	100	1170	479	103	1950	479	103	4200	105	75	0	0	0	8469	2840	474
1. Bench scale																								
a. Mechanisms & kinetics (BuMines)					30	35		46	46		46	46		46	46		46	46					214	219
b. Sorbent development & testing																								
(1) Development of new alkalized al.cat. (W.R. Grace)	359																					359		
(2) Preparation of improved alkalized al.cat. (BuMines)		25			50	58		54	54		58	57		58	57		29	29					274	255
(3) Poisoning by chlorine on alkalized al.cat. (BuMines)		20			30			30			30			30			30						170	
2. Pilot plant (BuMines)		897			250			345			345			345									2182	
3. Process evaluation & prototype design																								
a. Reactor modeling (AVCO)	184			70			70			70												394		
b. Process evaluation & conceptual design & improved prototype design (M.W.Kellogg)				266			100			200			200			200						966		
4. Prototype studies																								
a. CEGB fluidized bed version							100			900			250									1250		
5. Prototype improved American version													1500			4000						5500		
B. Limestone Processes	657	36	267	631	1468	279	4950	4575	509	280	1575	109	130	200	0	0	0	0	0	0	0	6648	7854	1164
1. Bench scale																								
a. Effectiveness of US limestone materials for sulfur col.	75			130			130			130			130									595		
b. Reaction kinetics of SO_2 with limestone (Battelle)	186			150			150															486		
c. Utilization of fly ash modified by SO_2 removal additives (W.Va. U.)	117						500															617		
d. Services contract for physical property measurement (Amer. Instrument)	15			20			20															55		
e. Effects of limestone physical properties on SO_2 reaction kinetics (TVA)		36			68			75			75												254	
2. Pilot plant																								
a. Reaction of SO_2 in flue gas with limestone in a fluidized bed (Esso)	191						150			150												491		
b. Pilot plant evaluation of limestone dolomite injection (Babcock Wilcox)	73			115																		188		

	Prior FY 1968			F Y 1 9 6 8			F Y 1 9 6 9			F Y 1 9 7 0			F Y 1 9 7 1			F Y 1 9 7 2			Post FY 1972			T O T A L		
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
c.Limestone additive studies in pilot plant furnace (BuMines)						40			109			109												258
d.Fabric filter as a contactor of SO_x in flue gas (Airpreheater Corp)				106																		106		
3. Prototype plant																								
a.Limestone-wet scrubber prototype (possibly Bechtel)				110			1500															1610		
b.Limestone process with dry reactor (best of pilot efforts-now visualized as fluidized bed)(Contractor unknown)							2500															2500		
4. Demonstration plant																								
a.Limestone injection with collection by electrostatic precipitator(TVA)					1400			2000			1500			200									5100	
b.Limestone injection with collection by wet scrubber (Unknown)								2500															2500	
c.Prevention of fireside boiler tube corrosion by addition of dolomite to coal (OCR-Combustion Eng)			267			239			400															906
C.Molten Carbonate Process (Second Generation Process for Stack Scrubbing	321	0	0	440	0	0	1684	0	0	1875	0	0	3575	0	0	0	0	0	0	0	0	7895	0	0
1.Bench scale process (Atomics Int)	321			217			494			75												1107		
2.Pilot plant process (Atomics Int)				123			265			400			125									913		
3.Prototype (design, construct, operate) (Atomics Int)				100			925			1400			3450									5875		
D.New Stack Treatment Processes *	846	30	0	3250	140	226	11250	100	358	16250	100	473	5250	100	530	4250	100	530	0	0	0	41096	570	2117
1.Exploratory & feasibility studies				2033			3000															5033		
2.Exploratory & supporting bench scale studies							8000			6000												14000		
3.Pilot plant										10000			5000			4000						19000		
Dry Metal Oxides																								
a.Applicability of metal oxides to development of new processes for removing SO_x from flue gas (Tracor)	208																					208		
b.Manganese oxide process for SO_2 control (BuMines)		30			40	18																	70	18
c.Exploratory studies and larger scale tests on selected absorbents (BuMines)				250	100		250	100		250	100		250	100		250	100					1250	500	
Aqueous Solution Scrubbing																								
a.Applicability of aqueous solutions to development of new processes for removing SO2 from flue gases (Aerojet-General)	254																					254		

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* New process studies will be conducted in each of the ten areas and may proceed through each of the three tasks under "New Process Studies," although this is unlikely. At each step, a review, analysis, and decision to proceed or cancel will be made. The amounts for each step are estimated requirements each year without regard to a specific area. The fall-out rate from step to step is expected to be (1) 50:1; (2) 10:1; (3) 5:1; (4) 3:1. The amounts on a specific area are actual known values up to a decision point. Explanatory information is contained in the supplements to the Program Element Summary Sheets.

	Prior FY 1968			F Y 1 9 6 8			F Y 1 9 6 9			F Y 1 9 7 0			F Y 1 9 7 1			F Y 1 9 7 2			Post FY 1972			T O T A L		
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Catalytic Oxidation																								
a.Applicability of catalytic oxidation to development of new processes for removing SO_2 from flue gases (Monsanto Research)				257																		257		
b.Catalytic oxidation of SO_2 with nitrogen oxide (TYCO)	42																					42		
Inorganic Liquids																								
a.Applicability of inorganic liquids to development of new processes for removing SO_2 from flue gases (MSA Res. Corp & Singmaster & Breyer)	65																					65		
Organic Liquids																								
a.Applicability of organic liquids to development of new processes for removing SO_2 from flue gas (unknown)				110																		110		
b.High temperature amine sorbents for SO_2 control (A.D. Little)	50																					50		
Inorganic Solids																								
a.Applicability of inorganic solids other than oxides to development of new processes for removing SO_2 from flue gases (Unknown)				150																		150		
Organic Solids																								
a.Applicability of organic solid sorption to development of processes for removing SO_2 from flue gases (Unknown)				150																		150		
b.Development of regenerative fibers for removing SO_2 from flue gases (Uniroyal)	40																					40		
c.Teller chromatographic process (BuMines)						58			58			173			230			230						749
Direct Reduction to Sulfur																								
a.Applicability of direct reduction to sulfur to the development of new processes for removing SO_2 from flue gases (Unknown)				150																		150		
b.Process to reduce SO_2 to S by sulfide reduction (Princeton Chemical)	84																					84		
Physical Methods																								
a.Applicability of physical methods of separation to development of new processes for removing SO_2 from flue gases (Unknown)				150																		150		
b.Process for removal of SO_2 from flue gases by fractional permeation through immobilized liquid membranes (General Electric)	103																					103		
Fertilizer Oriented Processes (TVA)						150			300			300			300			300						1350

	Prior FY 1968			FY 1968			FY 1969			FY 1970			FY 1971			FY 1972			Post FY 1972			TOTAL		
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
E. Process Design and Economic Evaluation of Flue Gas Treatment Processes	0	110	0	35	235	0	85	260	0	50	260	0	0	260	0	0	260	0	0	0	0	170	1385	0
1.Evaluation of processes for removal of SO_2 from flue gases (BuMines)		55			10			10			10			10			10						105	
a.Alkalized alumina based on latest BuMines pilot data or develop graphic of costs based on attrition rate (BuMines)																								
b.MnO process based on latest bench scale results (BuMines)																								
c.Teller process based on bench scale studies (BuMines)																								
d.Other selected processes (BuMines)																								
2.Conceptual design and economic evaluation of SO_2 control process (TVA)																								
a.Dry limestone injection-electrostatic precipitator collection (TVA)		55			45																		100	
b.Limestone injection-wet scrubbing collection (TVA)					90																		90	
c.Scrubbing SO_2 from stacks with ammonia solutions (TVA)					90																		90	
d.Other selected processes (TVA)								250			250			250			250						1000	
3.Cost utilization model-control of large new power plants (Battelle)				35			85			50												170		
II. STACK METEOROLOGY	0	50	0	358	30	0	471	200	0	400	200	0	400	200	0	350	0	0	0	0	0	1979	680	0
A.Plume Rise & Dispersion from Tall Stacks	0	50	0	300	30	0	450	200	0	400	200	0	400	200	0	350	0	0	0	0	0	1900	680	0
1.Develop hypotheses, models, instrumentation and plans		50		300	30																	300	80	
2.Apply & test hypotheses, collect data via actual field observations							450	200		400	200		400	200								1250	600	
3.Analyze & evaluate observations, develop conclusions																350						350		
B.Fate of SO_x (Geophysical Corporation of America) (non-add industrial funds)				58		(58)	21		(63)													79		(121)
III. FUEL DESULFURIZATION	407	145	0	507	130	633	2775	130	2506	4705	130	2012	4175	130	2044	3650	130	1924	6000	0	1100	22219	795	10222
A.Desulfurization of Residual Oil	60	0	0	100	0	100	300	0	650	500	0	550	0	0	600	0	0	600	0	0	550	960	0	3050
1.Exploratory & supporting studies																								
a.Economics of desulfurizing residual fuel oil (Bechtel)	60																					60		
b.Sulfur compounds in petroleum & petroleum products (BuMines)									250			250			200			200	(FY 73)		200			1100

	Prior FY 1968			F Y 1 9 6 8			F Y 1 9 6 9			F Y 1 9 7 0			F Y 1 9 7 1			F Y 1 9 7 2			Post FY 1972			T O T A L		
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
2.Bench scale																								
a.Catalytic hydrodesulfurization (BuMines)						100			100															200
b.Improved catalyst for hydro-desulfurization of residual oil (Hydrocarbon Research)				100			300			500												900		
3.Pilot plant																								
a.Hydrodesulfurization and treatment (BuMines)									300			300			400			400			350			1750
B.Desulfurization of Crude Oil	0	0	0	0	0	0	0	0	850	0	0	600	0	0	500	0	0	500	0	0	450	0	0	2900
1.Exploratory & supporting studies																								
a.Sulfur in petroleum (BuMines)									100			100			100			100			100			500
b.Applicability of solvent refining, clay treatment, hydrodesulfurization, etc. to desulfurizing crude (BuMines)									150															150
2.Bench scale																								
a.Pretreatment for sulfur removal (BuMines)									600			500			400			400			350			2250
C.Desulfurization of Petroleum Coke	0	0	0	0	0	0	0	0	250	0	0	100	0	0	100	0	0	100	0	0	100	0	0	650
1.Exploratory & supporting studies																								
a.Sulfur in petroleum coke (BuMines)									100			100			100			100			100			500
b.Applicability of various methods of desulfurizing petroleum coke									150															150
D.Desulfurization of Coal by Pyrite-Coal Process	347	145	0	307	130	0	1275	130	0	1005	130	0	575	130	0	50	130	0	0	0	0	3559	795	0
1.Survey & analysis																								
a.Feasibility of coal desulfurization & of iron & sulfur recovery from pyrite (Paul Weir)	27																					27		
b.Economic study of fluid bed roasting of pyrite-coal (A.D. Little & Dorr-Oliver)	67																					67		
c.Pyrite utilization & economic study (Bechtel & SRI)	93																					93		
2.Bench scale																								
a.Pyrite sulfur washability study (BuMines)		145			130			130			130			130			130						795	
b.Pyrite sulfur washability study (Commercial Testing & Eng. Co)	65			19			30			30												144		
c.Illinois coal evaluation (Ill. Geolog. Survey)	75						50			50												175		
3.Pilot plant (Bit. Coal Res.)	20			138			95			75			75									403		
4.Prototype (Unknown)				150			1100			850			500		50							2650		
E. New Systems & Physical Methods of Producing Low Pyrite Coal	0	0	0	0	0	536	0	0	756	0	0	762	0	0	844	0	0	724	0	0	0	0	0	3622
1.Feasibility and exploratory																								
a.Determination of sulfur modes in coal (BuMines)						78			35			35												148
b.Reduction of sulfur in steam coal (OCR-W.Va.Coal Res. Bur.)									100			150			100			150						500
c.Effect of crushing on magnetic properties of coal (BuMines)						29			52															81

	Prior FY 1968 A	B	C	F Y 1968 A	B	C	F Y 1969 A	B	C	F Y 1970 A	B	C	F Y 1971 A	B	C	F Y 1972 A	B	C	Post FY 1972 A	B	C	T O T A L A	B	C
2.Bench scale																								
a.Magnetic separation of pyrite using high frequency waves (BuMines)									80			115			460			290						945
b.Removal of pyrite & ash from coal by dry methods (BuMines)						63			63			63												189
c.Separation of pyrite from coal by electrostatic methods						78			92															170
d.Electrokinetic separation by pyrite from coal (BuMines)						46			69			104			58			58						335
3.Pilot plant																								
a.Removal of pyrite from coal by tabling (BuMines)						46			46			18			18			18						146
b.Desulfurization of coal by froth flotation (BuMines)						104			104			173			104			104						589
c.Washing fine sizes of coal using unconventional methods (BuMines)						46			46			46			46			46						230
d.Separation of pyrite from coal by centrifugal methods (BuMines)						46			69			58			58			58						289
F.New Fuel Desulfurization Processes *	0	0	0	100	0	0	1200	0	0	3200	0	0	3600	0	0	3600	0	0	6000	0	0	17700	0	0
1.Exploratory & supporting studies				100			300			300			500			500			800			2500		
2.Bench scale							300			500			700			700			2200			4400		
3.Pilot plant							600			2400			2400			2400			3000			10800		
IV.FUEL CONVERSION	96	0	20631	150	0	13369	7845	0	38299	15000	0	35353	15000	0	20248	15000	0	9540	0	0	1428	53091	0	138868
A.Molten Salt Gasification (OCR)	0	0	792	0	0	2678	500	0	4200	0	0	4650	0	0	1850	0	0	800	0	0	0	500	0	14970
1.Feasibility & exploratory study (M.W. Kellogg)			792			278	500															500		1070
2.Bench scale (M.W. Kellogg)						400																		400
3.Pilot plant (M.W. Kellogg)						2000			4200			4650			1850			800						13500
B.Hydrogasification	0	0	1678	0	0	2285	0	0	4300	0	0	3750	0	0	2500	0	0	1100	0	0	78	0	0	15691
1.Pilot plant																								
a.Effort of BuMines			822			285			400			450			500									2457
b.Joint effort of OCR,AGA			856			2000			3900			3300			2000			1100			78			13234
(AGA funds non-add)			(856)			(328)			(300)			(300)			(300)			(300)			(150)			(2534)
C.CO_2 Acceptor Process for Lignite Gasification (OCR)	0	0	907	0	0	1000	0	0	5350	0	0	3500	0	0	3200	0	0	800	0	0	0	0	0	14757
1.Laboratory (Consolidation Coal)						200			200															400
2.Bench scale (Consolidation Coal)			907			500																		1407
3.Pilot plant (Consolidation Coal)						300			5150			3500			3200			800						12950
D.Gasification Optimization (OCR) (W. Va. U)	0	0	15	0	0	30	0	0	70	0	0	48	0	0	0	0	0	0	0	0	0	0	0	163
E.Fixed Bed Gasification	0	0	650	0	0	280	0	0	330	0	0	330	0	0	500	0	0	350	0	0	350	0	0	2790
1.Bench scale (BuMines)			650			100			90															840
2.Pilot plant (BuMines)						180			240			330			500			350			350			1950

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* New studies conducted under this program may proceed through each of the three tasks, although this is unlikely. At each step a review, analysis, and decision to proceed or cancel will be made.

	Prior FY 1968			F Y 1 9 6 8			F Y 1 9 6 9			F Y 1 9 7 0			F Y 1 9 7 1			F Y 1 9 7 2			Post FY 1972			T O T A L		
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
F.Sulfur Control by Means of Coal Gasification (Scientific Res. Inst.)	96	0	0	0	0	0	95	0	0	0	0	0	0	0	0	0	0	0	0	0	0	191	0	0
G.Synthetic Pipeline Gas from Coal (OCR)	0	0	1425	0	0	600	0	0	4000	0	0	2800	0	0	2200	0	0	400	0	0	0	0	0	11425
1.Laboratory (Bituminous Coal Res.)			1425			300			450			150												2325
2.Bench scale (BCR)						100			150			350												600
3.Pilot plant (BCR)						200			3400			2300			2100			200						8200
4.Commercial design (BCR)															100			200						300
H.Catalytic Methanation (BuMines)	0	0	570	0	0	120	0	0	160	0	0	250	0	0	200	0	0	450	0	0	500	0	0	2250
1.Bench scale			570			120			160															850
2.Pilot plant												250			200			450						900
3.Prototype																					500			500
I.Production of Synthetic Crude Oil from Coal (GASOLINE) (OCR)	0	0	9212	0	0	2625	0	0	3729	0	0	5225	0	0	2730	0	0	100	0	0	0	0	0	23621
1.Pilot plant			9212																					9212
a.CFS (sand catalyst)(Consolidation Coal)						2125			2029			2225			600									6979
b.Zinc Chloride (Consolidation Coal)						500			1700			3000			2130			100						7430
J.Fluidized Coking of Resid-Coal to Yield Liquid & Solid Boiler Fuel (SEACOKE) (OCR)	0	0	522	0	0	378	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	900
1.Laboratory (ARCO)			522			378																		900
K.H-Coal Process (OCR)	0	0	1526	0	0	1248	0	0	8000	0	0	8250	0	0	3500	0	0	3500	0	0	500	0	0	26524
1.Bench scale (Hydrocarbon Res.)			1526			374																		1900
2.Pilot plant (Hydrocarbon Res.)						874			8000			8250			3500			3500			500			24624
L.Char-Oil-Energy Development-(COED)(OCR)	0	0	2134	0	0	725	0	0	4590	0	0	4050	0	0	1168	0	0	40	0	0	0	0	0	12707
1.Laboratory & bench scale (FMC)			2134			600						470			260									3464
2.Pilot plant (FMC)						125			4590			3580			908			40						9243
M.Low Ash Coal (OCR)	0	0	1200	0	0	1400	0	0	3570	0	0	2500	0	0	2400	0	0	2000	0	0	0	0	0	13070
1.Laboratory & bench scale (Pgh Midway Coal Mining Co.)			1200			220			100															1520
2.Pilot plant (Pgh Midway Coal Mining)						1180			3470			2500			2400			2000						11550
N.Solvent Refined Coal (Technical & Economic Evaluation)	0	0	0	0	0	0	250	0	0	0	0	0	0	0	0	0	0	0	0	0	0	250	0	0
O.Refuse as a Low Sulfur Fuel	0	0	0	150	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	150	0	0
1. Exploratory and feasibility studies				150																		150		
P.Undesignated Fuel Conversion Projects	0	0	0	0	0	0	7000	0	0	15000	0	0	15000	0	0	15000	0	0	0	0	0	52000	0	0
V.NEW COMBUSTION PROCESSES	0	0	2644	60	0	1800	2150	0	3685	5002	0	5510	5000	0	4770	0	0	5000	0	0	8700	22212	0	32109
A.Fluidized Bed Combustion	0	0	444	60	0	440	150	0	435	2	0	50	0	0	0	0	0	0	0	0	0	212	0	1369
1.Pilot plant																								
a.For high heat release (OCR) (Pope, Evans, & Robbins)			444			300			315			50												1109

	Prior FY 1968			FY 1968			FY 1969			FY 1970			FY 1971			FY 1972			Post FY 1972			TOTAL		
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
b.For high heat release (BuMines)						140			120															260
c.For air pollution control (OCR) (Pope, Evans, Robbins)				60			150			2												212		
B.Coal Conversion to Electricity (BuMin)	0	0	0	0	0	235	0	0	250	0	0	260	0	0	295	0	0	0	0	0	0	0	0	1040
C.Fuel Cells (OCR)	0	0	2200	0	0	1125	0	0	3000	0	0	5200	0	0	4475	0	0	5000	0	0	8700	0	0	29700
1. Feasibility & lab (OCR) (Westinghouse)			2200			1000			1000															4200
2.Bench scale (OCR)(Westinghouse)						125			2000			4500			2175			1000						9800
3.Pilot plant (OCR)(Westinghouse)												700			2300			4000			8700			15700
D.Undesignated New Combustion Processes							2000			5000			5000			5000			5000			22000		
VI.INDUSTRIAL PROCESS CONTROL	0	0	0	882	0	0	1700	0	0	6150	0	0	26000	0	0	31000	0	0	0	0	0	65732	0	0
A.Non-Utility Process Control (General)	0	0	0	882	0	0	1700	0	0	6150	0	0	26000	0	0	31000	0	0	0	0	0	65732	0	0
1.Industrial surveys & control feasibility studies							200			150												350		
2.Exploratory & supporting bench scale studies							500			1000			1000			1000						3500		
3.Pilot plant										5000			10000			10000						25000		
4.Prototype/Demonstration													15000			20000								
Non-Ferrous Smelting Industry																								
a.Survey of primary copper, lead & zinc smelting (Arthur G.McKee)				382																		382		
Coke Manufacturing Industry Survey																								
a.Survey of by-product & beehive coke ovens for pollution control (Unknown)							250															250		
Integrated Iron and Steel																								
a.Survey of integrated iron & steel mills				250																		250		
Sulfuric Acid																								
a.Survey of sulfuric acid industry for SO_2 emissions control (Unknown)							250															250		
Petroleum Refining Industry																								
a.Survey of petroleum refining system for optimum SO_2 emission control							250															250		
Pulp & Paper Manufacturing																								
a.Survey of pulp & paper air pollution problem and control development needs (Unknown)				250																		250		
Industrial & Commercial Boilers																								
a.System analysis of control methods for stationary combustion units							250															250		

	Prior FY 1968			F Y 1 9 6 8			F Y 1 9 6 9			F Y 1 9 7 0			F Y 1 9 7 1			F Y 1 9 7 2			Post FY 1972			T O T A L		
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
VII. FUEL AVAILABILITY SURVEYS	0	55	105	100	172	340	720	460	1136	720	390	270	620	50	520	550	0	500	550	0	500	3260	1127	3371
A. Availability of Low Sulfur Coal (BuMines)	0	55	0	0	152	76	300	410	76	300	340	100	200	0	500	200	0	500	200	0	500	1200	957	1752
B. Development of Special Purpose Coals (OCR) (Penn State U)	0	0	105	0	0	254	0	0	1040	0	0	150	0	0	0	0	0	0	0	0	0	0	0	1549
C. Availability of Natural Gas as Substitute for Low-Sulfur Fuel (FPC)	0	0	0	0	20	10	0	50	20	0	50	20	0	50	20	0	0	0	0	0	0	0	170	70
D. Technology & Availability of Liquified Natural Gas (Unknown)	0	0	0	50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	50	0	0
E. Availability of Various Grades of Oil for Different Idealized Refining Modes	0	0	0	50	0	0	70	0	0	70	0	0	70	0	0	0	0	0	0	0	0	260	0	0
F. Undesignated Fuel Availability	0	0	0	0	0	0	350	0	0	350	0	0	350	0	0	350	0	0	350	0	0	1750	0	0
VIII. SUPPORTING INSTRUMENTATION DEVELOPMENT	0	0	0	0	0	0	500	0	0	500	0	0	500	0	0	0	0	0	0	0	0	1500	0	0
A. Development of Instrumentation for SO_x Control Activities	0	0	0	0	0	0	250	0	0	250	0	0	250	0	0	0	0	0	0	0	0	750	0	0
1. Develop specifications for ambient air monitoring instrument																								
2. Design, development, and testing of instruments																								
B. Process Instrumentation & Control	0	0	0	0	0	0	250	0	0	250	0	0	250	0	0	0	0	0	0	0	0	750	0	0
IX. PROGRAM DEVELOPMENT, ANALYSES, AND EVALUATION	223	0	0	560	0	0	1100	0	0	1400	0	0	1400	0	0	1400	0	0	0	0	0	6083	0	0
A. General Planning Studies	23	0	0	135	0	0	500	0	0	700	0	0	700	0	0	700	0	0	0	0	0	2758	0	0
1. Simulation approach to air pollution abatement (Ernst & Ernst)	23			75																		98		
2. Comprehensive program planning study for SO_x control (SRI)				60																		60		
B. Program Development, Implementation and Control	200	0	0	425	0	0	600	0	0	700	0	0	700	0	0	700	0	0	0	0	0	3325	0	0
TOTAL SO_x CONTROL PROGRAM	3093	1368	23647	7309	2535	16743	35500	6200	46593	53502	3134	43830	64000	1419	28215	65400	595	17569	11550	0	11728	240354	15251	188325

Chapter I

THE SULFUR OXIDE POLLUTION PROBLEM

A. Introduction

Air pollution is one of the unfortunate byproducts of an urban, technological, and industrial society. It is a complex national problem with far reaching and incompletely defined economic, social, and technological ramifications. Although control efforts are often beset by conflicting interests, parochial judgments, and contradicting claims, the control of air pollution is now a national objective.

Virtually all the nation's activities that utilize materials for domestic, commercial, agricultural, industrial, and other purposes discharge contaminants to the air. The burning of fuels to heat homes and to propel automobiles, trains, planes, and missiles; the conversion of raw materials into finished goods; the application of pesticides and fertilizers to increase crop yields; the burning of trash and garbage; the clearing of land; the construction of roads and buildings--all of these put foreign substances into the atmosphere. In 1965 about 142 tons of pollutants were emitted into the air by the sources listed in Table 1.

As a result of our abundant use of sulfur-containing fossil fuels to produce power and heat, the emissions of sulfur oxides rank second among total pollutant emissions in this country.

This report is concerned with the substantial effort now underway to develop improved technology for control of sulfur oxides pollution.

B. Sulfur Oxides Pollution

In 1966, the total emission of sulfur oxides into the atmosphere from stationary sources is estimated to have increased to approximately 29,000,000 tons from the 26,000,000 tons estimated in 1965 as shown in Table 1.

The distribution of these emissions from the different sources is presented in Table 2. Some 85% of the total resulted from the combustion of fossil fuels, with combustion of coal being responsible for 60%. Next to combustion, the largest emission category was the smelting of the sulfide ores of copper, lead, and zinc.

Table 1

NATIONAL SOURCE DISTRIBUTION FOR SELECTED AIR POLLUTANTS IN MILLIONS OF TONS PER YEAR - 1965

	Carbon Monoxide	Sulfur Oxides	Nitrogen Oxides	Hydro-carbons	Particulate Matter	Totals
Motor Vehicles	66	1	6	12	1	86
Industry	2	9	2	4	6	23
Power Plants	1	12	3	1	3	20
Space Heating	2	3	1	1	1	8
Refuse Disposal	1	1	1	1	1	5
Totals	72	26	13	19	12	132

Source: "Sources of Air Pollution and their Control," USDHEW, Public Health Service - 1966.

C. Sources of Sulfur Oxides Pollution

The total contribution figures presented in Table 2 do not in themselves give an adequate assessment of the relative importance of the various sources. Much depends on the individual characteristics of the emission sources, such as size of the plant and height of the stack. Many individual emission sources that are minor in terms of percentage of the total emissions may present severe air pollution problems in their own areas. The major classes of sulfur oxides sources are discussed briefly in the following paragraphs.

1. Electrical Power Generation

Fossil-fuel-fired power plants are responsible for about 46% of the total sulfur oxides emissions, nearly 42% coming from coal-fired power plants. These emissions are unevenly distributed throughout the country. Over 60% of the sulfur oxides from the burning of coal by utilities is emitted in eight states of the East North Central and East South Central regions. In the Middle Atlantic and South Atlantic states, the utility fuel used inland is generally high-sulfur coal; in a shallow region along the coast, relatively large quantities of residual oil that is also high in sulfur content are generally used.

Table 2

EMISSIONS OF SULFUR OXIDES FROM STATIONARY SOURCES - 1966

Source	% of Total Emission	
Electrical Power Generation		
Coal	41.6	
Oil	4.3	
Total Power Generation		45.9
Other Combustion Operations (Industrial, Commercial, Residential)		
Coal	16.6	
Oil	15.3	
Total Other Combustion Operations		31.9
Smelting of Ores		12.2
Miscellaneous		
Oil Refining	5.5	
Coke Processing	1.8	
Sulfuric Acid Manufacture	1.9	
Coal Refuse Banks	0.4	
Refuse Incineration	0.4	
Gas	0.04	
Other (Pulp and paper mills, chemical manufacture, etc.)	0.05	
Total Miscellaneous		10.8
		100
Total Coal	60.0	
Total Petroleum	25.1	
Total Gas	0.04	
	85.2	

Source: "Sources of Air Pollution and their Control," USDHEW, Public Health Service - 1966

Throughout most of the West and Southwest, the principal utility fuels are natural gas and low-sulfur coal, and the sulfur oxides problem is thus far less acute. The operation of very large coal-fired generating plants is increasing, however, and, in some Western locations, the total sulfur emissions and resulting ground-level concentrations may exceed the desired air-quality standards. Therefore, even though the sulfur contents of the coals used are relatively low, the need for control of these sources may still arise.

In most geographic locations, the use of nuclear fuel for power generation is expected to reduce somewhat the rate of increase of sulfur oxides pollution in the next 20 years. Power demands are expanding so rapidly, however, that a nationwide increase in emissions cannot be forestalled by this means alone. Stack-gas treatment and fuel pretreatment processes are considered most likely for effective control of sulfur oxides from electrical power generation.

2. Industrial Fuel Combustion

Consumption of fossil fuels by industries for the generation of power and steam and for process heating and space heating is much greater than the consumption by utilities. The total sulfur oxides emission is lower, however, because about half of the fuel consumed is natural gas. Industrial use of oil is relatively much greater than that by utilities. Current trends in fuel demand are toward increased use of natural gas and a leveling off of the use of coal and oil. Use of high-sulfur fuels by industry follows the same geographical pattern noted for consumption of such fuels by public utilities.

In view of the large number, relatively small size, and extreme diversity of industrial combustion operations (many of which also face severe space constraints), it is unlikely that stack-gas treatment will be practical for control of emissions for most of these operations. Nuclear power is not a feasible substitute for fossil fuels at these installations. Nevertheless, the total sulfur oxides emissions from industrial, commercial, and residential combustion sources represent a large component (32%) of the total problem and must be controlled. For the industrial sources, fuel substitution represents the only practical method of control at the present time. For areas in which the possibilities of fuel substitution are limited, processes for fuel pretreatment or combustion system modification must be developed.

3. Commercial and Residential Fuel Combustion

The commercial and residential requirement for fuels for space heating, industrial processing, and such equals the requirement for fuels used by the utility industry in the production of electrical energy. However, the major sources of utility fuels are coal and oil, while for the commercial and residential sector, natural gas supplies about two-thirds of the fuel demand, oil supplies about one-fourth, and coal and other fuels make up the balance. The use of coal is relatively small in all regions. Residual fuel oil is used for space heating in some large buildings on the Atlantic seaboard, but most of the oil consumed is distillate fuel oil having relatively low sulfur content. Most of the sulfur oxide emissions from commercial and residential sources result from combustion of the fuel oil.

For control of the commercial and residential sources, only fuel substitution offers a practical approach. Where adequate supplies of low-sulfur fuels are not readily available, methods for desulfurization of high-sulfur fuels must be made available. Even the distillate fuel oils, despite their relatively low sulfur content, account for substantial sulfur emission because of the large total consumption.

4. Smelting of Ores

The relative contribution of smelting to the total emission of sulfur oxides has increased since 1963, primarily because of the increased production of copper from low-grade ore. Because smelters are large individual sources of emission, they are often responsible for damage to agricultural crops and forests.

A number of smelters produce sulfuric acid from their waste gases. Sulfuric acid can be shipped economically for only limited distances, however, and some of the largest smelters are located in areas where existing markets cannot accommodate all of the acid that could be produced. Consequently, large amounts of the sulfur oxides are still being discharged to the atmosphere.

There is a need for economical processes for converting the sulfur oxides in smelter waste gases to elemental sulfur, which can be shipped to distant markets. Alternatively, it may be possible to develop markets for sulfuric acid by encouraging production of fertilizer in regions near smelters.

5. Oil Refining

The emission of sulfur oxides from oil refining (estimated to constitute 5.5% of the total) results primarily from fuel combustion and could therefore be classified with the other industrial combustion operations. A relatively small part of the emission comes from such processes as the regeneration of cracking catalysts; the greatest part comes from combustion of residual oil and refinery gas in process heating. The sulfur in the refinery gas is present in the form of hydrogen sulfide, and well-developed processes are available for recovering the hydrogen sulfide before the gas is burned; the hydrogen sulfide can be converted either to sulfuric acid or to elemental sulfur. Such recovery is frequently practiced at oil refineries for economic reasons as well as for air pollution control.

The combustion of residual oil, which supplies about one-tenth of the total of fuel demand of U.S. refineries, presents the same type of emission problem as does residual oil combustion in utility or other industrial operations.

6. Coke Processing

Most coke is produced for use in iron and steel manufacture. The principal source of sulfur oxide emissions (estimated currently at 1.8% of the total) is the combustion of the hydrogen sulfide in the coke-oven gas used as fuel. In recovery-type (or slot) coke ovens, the hydrogen sulfide can be recovered from the gas (and sometimes is) by the same processes used to recover it from refinery gases. For economic reasons, sulfur recovery is often not practiced, but the means are readily available.

Because of the decline in the need for coal tar as a source of chemicals, there is a reported increase of interest in nonrecovery ovens in which all the tar and gas would be burned to supply heat. Provisions for recovery of the sulfur should be included in new ovens of this type, but may be omitted in the absence of effective regulations to limit sulfur oxide emissions. In such cases, sulfur-recovery equipment would have to be added at a future time.

Beehive ovens are still in use, although the number in service is continually declining. In 1966, only 2.5% of the total U.S. production of coke came from beehive ovens. The gross value of this coke was only 1.4% of the value of all the coke produced, or slightly over $13,000,000. Beehive ovens are copious producers of air pollutants other than sulfur oxides. Since the units in existence are old and obsolete, the effect of air pollution regulations will probably be to accelerate the rate of retirement.

7. Sulfuric Acid Manufacture

In the conventional contact process for manufacture of sulfuric acid, about 2% to 4% of the SO_2 is not converted to SO_3 and recovered as sulfuric acid, but instead escapes to the atmosphere. These SO_2 emissions are estimated to constitute 1.9% of the total annual sulfur oxides **emission**. This concentration of SO_2 in the tail gases from acid plants is fairly low, but generally higher than in the flue gases from combustion of coal and oil.

Two methods are now in use for reduction of the emissions of SO_2 in tail gases. One method yields a byproduct (ammonium sulfate) and concentrated sulfuric acid, which is returned to the plant. The other method converts SO_2 to SO_3 and then recovers the sulfur as sulfuric acid.

8. Coal Refuse Banks

Burning coal refuse banks located at coal mines are a source of sulfur oxides emission, estimated to be 0.4% of the total. The contribution from this source is reported to be decreasing as old fires are extinguished and as better practices are used in constructing new refuse piles to prevent spontaneous combustion.

9. Refuse Incineration

Refuse incineration (a principal point of interaction between air pollution and solid waste disposal) is estimated to contribute 0.4% of the total sulfur oxides emission. Since the sulfur content of municipal refuse is generally very low, this source does not present a serious problem of sulfur oxides emission; however, refuse incineration in urban areas can produce severe local air pollution problems entailing other pollutants. The possibility of treating solid wastes as a low-sulfur fuel for power production in high-efficiency boilers is being explored and deserves further investigation.

10. Pulp Mills

Pulp mills contribute only a very small fraction to the total emission of sulfur compounds, but many of these, even at low concentration, present local problems because of their odorous qualities. In kraft, or sulfate, pulp mills, the black-liquor recovery furnace generally emits SO_2 at low concentrations in comparison to those from burning fuels of moderate sulfur content. If necessary, the SO_2 could be recovered by integration of a gas absorption system with the dust collection system. The largest source of sulfur oxides emissions from kraft mills is probably the combustion of residual oil for power and steam generation, roughly in the same category as other industrial combustion operations.

At sulfite pulp mills, SO_2 is often emitted at relatively high concentrations during discharge of the pulp digesters. Some mills now employ recovery processes for the SO_2 both for air pollution control and for reasons of economy. Potential sources of SO_2 emission will increase as the need for water pollution control forces sulfite mills to switch to combustion of sulfite waste liquors; however, recovery of the SO_2 for recycle will be an integral part of the process.

D. Legislative History and Congressional Action

As the air pollution situation has grown progressively worse, the public has become increasingly conscious of this phenomenon and more concerned about it. This concern is well founded. At the present emission levels, we are already experiencing demonstrable adverse effects: damage to human health, destruction of property, and reduction of visibility. The extent of these effects is not completely defined; it is abundantly clear, however, that the problem is great, that it is growing, and that solutions are needed now.

In July 1955, Congress responded to public concern for the national health and welfare by enacting legislation that authorized a Federal program of research in air pollution and technical assistance to state and local governments.

In this legislation, Congress established the policy that state and local governments have a fundamental responsibility for dealing with community air pollution problems, and further, that the Federal Government has an obligation to provide leadership and support. This policy remains in effect, although the ways in which the Federal Government can help have undergone marked change.

In the first 8 years following the creation of the Federal program, its activities helped to take much of the mystery out of the modern air pollution problem. In direct and indirect ways, the Federal effort substantially increased both scientific knowledge and public awareness of the nature and extent of the air pollution problem, the impact on public health and welfare, techniques for controlling many important sources of air pollution, and the need for new and better techniques. The Federal research effort showed that progress toward better understanding of the problem was not being matched by real progress toward better control.

To remedy this situation, Congress passed the Clean Air Act in 1963. This Act authorized three major new Federal activities in support of air pollution control efforts across the country: the awarding of grants directly to state and local agencies to assist them in developing, establishing, or improving control programs; Federal action to abate interstate air pollution problems, which are essentially beyond the reach of individual states and cities; and direct Federal action to abate pollution from motor vehicles.

Among other provisions, the Clean Air Act called for a program of research, directed toward the development of improved, low-cost techniques for extracting sulfur from fuels. In 1965, this mandate was extended to include "development of low-cost techniques designed to reduce emissions of oxides of sulfur produced by the combustion of sulfur-containing fuels". Note here the strong Congressional interest in technological and economic feasibility of controlling sulfur production. With this legislation came the first substantial appropriations on a level consistent with the magnitude of the problem. These funds were used to lay the groundwork for large-scale studies leading toward a "first generation" of control techniques.

In 1967, the Air Quality Act was passed. This Act provides a blueprint for a systematic effort to deal with air pollution problems on a regional basis. It calls for coordinated action at all levels of government and among all segments of industry.

Under this Act, the Department of Health, Education, and Welfare will define the broad atmospheric areas of the Nation and will designate specific air quality control regions. The Department will develop and publish air quality criteria indicating the extent to which air pollution is harmful to health and damaging to property and detailed information on the cost and effectiveness of techniques for preventing and controlling air pollution.

As soon as air quality criteria and data on control technology are made available for a pollutant or class of pollutants, states will be expected to begin developing air quality standards and plans for implementation of the standards which will be applied on a regional basis.

If a state fails to establish standards, or if the Secretary of Health, Education, and Welfare finds that the standards are not consistent with the Act, he can initiate action to insure that appropriate standards are set. States will be expected to assume the primary responsibility for application of the air quality standards. If a state's efforts prove inadequate, the Secretary is empowered to initiate abatement action. Through this mechanism, the Air Quality Act is intended to bring about the abatement of the many sources of pollution for which feasible control techniques are available.

In its other major thrust, the Air Quality Act provides for a greatly increased effort on development of control technology, with special emphasis on techniques for controlling pollution from combustion of fuels. Congress recognized that abatement efforts on the state and regional level must be backed up with control techniques much more effective than those available today. This development effort cannot be limited to in-house projects conducted by Federal agencies; rather, the Government must marshal the total technological resources of the Nation, encompassing those of all concerned Federal groups and of the industrial community. Since it was clear that this expanded effort called for overall direction through a single highly coordinated program, the President, early in 1967, designated to the Secretary of Health, Education, and Welfare the responsibility for leadership, at the same time calling for a greatly accelerated sulfur control program.

E. Future SO_x Environment

Planning a substantial program of research and development calls for a comprehensive overview to define and delineate the problems, the objectives, and the alternatives; finally, one must designate the studies needed to accomplish the objectives in a programmed manner. Then the technical work begins, and the research and development cycle progresses from laboratory to bench scale to pilot plant to prototype and possibly to the demonstration stage. In all of this development, the more complex the problem and the more complicated the equipment, the greater is the time required to reach the working stage.

When hardware for process control is developed, the consumer must be advised, variations tailored to specific applications, the equipment constructed, and its integration into the process successfully demonstrated. Only after all of this is completed, can the equipment be put to use on-stream.

If research and development are planned on the basis of today's needs, the equipment produced 10 to 20 years from now will meet today's needs, but will continue to perform a valuable function only if the environment undergoes little change. Since today's world is not static, we must assume that environmental change will occur and try to predict the forms such change will take. Although the urban air environment with respect to sulfur oxides cannot be forecast, some facts are known, some trends are evident, and some events can be anticipated.

An important foreseeable modification in the rate of increase of unabated sulfur oxide in the environment can result from the increased use of nuclear power. Figure 1 shows the incursion of nuclear power in the production of the total electrical energy requirement of the U.S. in the future. This is an upward revised estimate of the Atomic Energy Commission based on a past experience of consistently underestimating the growth in the use of nuclear power to generate electrical energy.

Underestimation may persist if new technology improves the efficiency of converting nuclear energy to electrical power, or if new economical nuclear fuel sources are discovered. Nevertheless, lower estimates by other groups have been published, and considerable controversy exists concerning the future growth of nuclear energy.

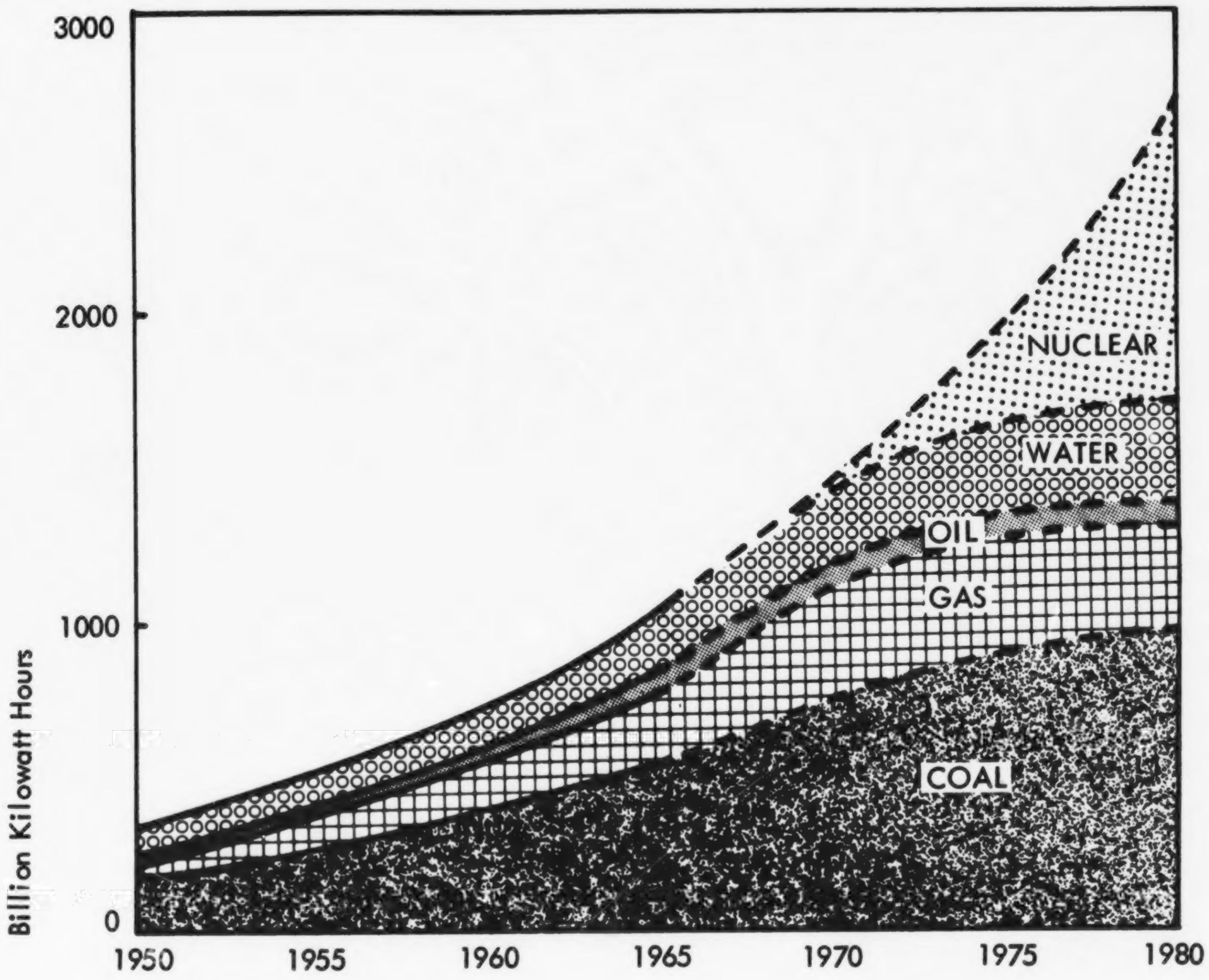
Uncertainty is caused by the constraints on the use of nuclear energy. The known supply of economically usable uranium appears limited and could be fully committed by 1980 at the present rate of growth of nuclear power plants. The time at which breeder reactors can be brought into balance to effectively supplement nuclear fuel is estimated to be late in the century, although the initial date of breeder reactor operation may occur in the next 5 to 10 years. The rate of growth in orders for new nuclear power plants is already showing a strain because of limitations in expanding the capacities in construction and trained, capable manpower. Using the most optimistic estimate of the AEC, one notes that the use of coal and oil for production of power will increase in the future. Correspondingly, the fossil fuel industry itself estimates an increased use of fossil fuels even with the expected growth of nuclear power, because the projected growth of total energy exceeds the growth capabilities currently foreseen for nuclear power. This point also can be seen in Figure 1. Note that estimated use of coal and oil in the future far exceeds current use. Sound reason exists for this. Use of nuclear power is competitive with that of fossil fuels only at very large plant sites and at sites able to handle the additional water requirements of a nuclear power system. Demand for production of energy from intermediate scale fossil fuel units, or in large mine-mouth boilers, is expected to continue because of favorable economics. Furthermore, the production of electrical energy represents only 46% of sulfur oxide emission, as shown in Table 2. Although the advent and growth of nuclear power is expected to cause dislocations in the energy field, it is not expected to change the fundamental nature of the sulfur oxides emission problem with respect to the combustion of fossil fuels in the utility industry, commercial, and residential markets; or the need for the variety of sulfur oxide control techniques for all types of combustion operations, smelting of ores, and numerous other miscellaneous sources. The mix of control techniques may change with general technological developments in the future, but the demand for a wide variety of control techniques is foreseen for the distant future as well as the near future.

Another important environmental change is the tendency of the power industry to build larger power plants. Most of the plants being constructed today are designed for a capacity greater than 500 MWe; this trend is expected to continue, especially in areas near sources of fuel such as

Figure 1

ENERGY SOURCES FOR ELECTRIC POWER

Source: "The Nuclear Industry," U.S. Atomic Energy Commission



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at the mine mouth. Certainly this phenomenon will affect the planning of future stack-gas treatment.

In addition, future breakthroughs in new fuel forms and new energy cycles that incorporate sulfur oxides control would have an enormous effect on the sulfur oxides environment. Examples of new fuel forms are the conversion of coal into nonsulfurous form by gasification or liquefaction, and the use of oil shale. Fuel cells and magnetohydrodynamics (MHD) processes represent possible new energy cycles.

Other possible changes should be considered. For example, atomic energy may be used to free large deposits of natural gas. Thus, the resource base for this sulfur-free fuel will be enlarged. Secondly, the use of elemental sulfur will exhaust known supplies from natural deposits by 1990. As natural supplies become scarce (a condition felt even today as evidenced by depleted above-ground inventories), supplemental supplies will be sought. Stack scrubbings of combustion units become potential economical sources for this needed supply.

F. Research and Development Logic

With the funds and the authority to exercise leadership in an accelerated sulfur pollution control effort, the Department of Health, Education, and Welfare, through its operating program in the National Center for Air Pollution Control, assumed management responsibility for a comprehensive research and development program. Giving logical form to such a broad-scale program required cognizance of all the interacting forces and of their time-dependence.

1. The Changing Objective

With the time element in mind, one may categorize the objectives of the sulfur oxides R&D program in three phases. The first phase dates from the mid-1950's until the early 1960's, when the seriousness of the SO_x problem was recognized and the first air pollution alarms were sounded. The research and development objective of Federal programs during this first phase was to establish a technological data base. Efforts were directed to determining the nature and extent of the problem and to defining the mechanisms by which pollutants cause damage. For all practical purposes, this first phase can be considered completed.

The Federal program then moved into its second and current phase. The passage of air pollution legislation in 1963, 1965, and 1967 encouraged the National Center for Air Pollution Control to accelerate development of sulfur oxides control technology, to stimulate commercial interest in a similar development effort, and to conduct joint Government-industry research and development. Before 1966, little Federal funding was available to support joint undertakings. Most of the Government's research and development up to that time had been restricted to the intramural efforts of the NCAPC and the Bureau of Mines, with some spin-off from projects supported by the Office of Coal Research and TVA. When funds became available in 1966, the Government immediately undertook participation with the commercial sector in developmental efforts. Currently, the NCAPC is sponsoring work by more than 20 industrial groups, research firms, and other non-Government organizations. From now until the mid-1970's in this second phase, the Government's role will be to continue its own research and to encourage a growing industrial participation in the sulfur oxides control program. Self-supporting industrial participation is expected to increase with the establishment of air quality control regions and air quality standards as provided by the 1967 Air Quality Act. Implementation of this Act will generate significantly increased markets at the local level for commercial suppliers of control equipment.

The third phase is visualized as a period in which the Government will perform research and development technology at a much reduced level; the bulk of the work will have been taken over by commercial suppliers attracted by profit potentials. The Government's efforts in this phase will be concentrated on longer-range programs for control technology, on research to support development of new air quality criteria and standards, and on development of more effective means of monitoring and operating pollution abatement programs.

2. Current Option

In the current phase of the program, the aim is to develop control techniques that can be applied before, during, and after the formation of sulfur oxides. Five areas of control are being explored: (a) substitution of fuels; (b) pretreatment of fuels; (c) stack gas treatment; (d) stack meteorology; and (e) process change.

(a) Substitution of Fuels. The most immediate method of preventing the formation of sulfur oxides involves the substitution of fuel materials containing little or no sulfur. There are, of course, constraints to this approach. The known reserves of both natural gas and uranium are limited, and most of the coal and oil used in this country is not low in sulfur content. Moreover, the extent of the Nation's reserves of these low-sulfur fuels is unknown, as is the cost of procuring them. Further, one must consider the social, political, and economic consequences of severely altering the current fuel usage patterns.

In any event, the substitution of fuels is the major control technique in use today, and it offers some promise as a short-term expedient in critical areas until other control methods become available.

(b) Pretreatment of Fuels. Desulfurization of oil using existing techniques is possible. Improved, less expensive methods that eliminate most of the sulfur in residual oil have been developed and should be available for commercial use by 1970. Limitations of this approach include import quotas on oil, and the economic feasibility of shipping residual oil great distances inland.

Technically, the desulfurization of coal remains a more difficult problem. A process currently under development is expected to eliminate most of the pyritic sulfur in some coal deposits and therefore will be beneficial for those high-sulfur coals in which the pyritic sulfur is amenable to removal. In many cases involving fuels of high organic sulfur content, this process cannot be utilized to yield low-sulfur coal. Another possibility is the transformation of conventional coal into some other virtually sulfur-free physical form by gasification, liquefaction, or solvent refining processes. Both the cost and the anticipated effectiveness of these processes are basically nebulous quantities at the present stage of development; additional data are needed.

(c) Stack Gas Treatment. Another approach is to treat the stack gases in a way that removes most of the sulfur oxides before the gas reaches the atmosphere. There are numerous possible processes for accomplishing this objective, and substantial research and development resources are now committed to this area. Besides considerable technical difficulties still to be overcome, the development work must allow for plants of various sizes and ages, spatial and structural limitations, availability of local natural resources, anticipated markets for byproducts, and other factors. The effectiveness and the cost of these processes are still to be precisely defined.

(d) Stack Meteorology. The basis of this approach is the construction of tall stacks that permit dilution of the sulfur oxides in the air and that, for some meteorological regions, result in lower ground-level concentrations near the source. Limitations include possible local topographic and meteorological conditions, which sometimes constrain the quantities of sulfur oxides that can be emitted in a region. This method does not reduce emissions to the atmosphere but merely disperses the plume into a larger volume of air. Stack meteorology requires more study to further define dispersion mechanisms under varying conditions.

(e) Process Changes. This technique encompasses the alteration of combustion processes to prevent or decrease the release of sulfur oxides and the modification of smelting or industrial processes, either to facilitate stack gas treatment or to eliminate the formation of sulfur oxides. Again, cost and effectiveness data are lacking, and much technical work remains to be done.

G. Impact of Sulfur Oxides in Other Areas

Just as secondary benefits are obtained from work not aimed primarily at SO_x control, so many probable "side" benefits can be expected from the SO_x control program. Air pollution control programs have already derived value from development work performed in nuclear power and space programs. Similarly, SO_x control development will generate concepts, data, and techniques that can be applied elsewhere. This particular Federal program may aid, although incidentally, in bringing about higher-efficiency, lower-cost production of power using fossil fuels. One example appears in the development of the fluidized combustion furnace using dolomite or similar materials for control of SO_x. The furnace also provides a greater heat release than conventional furnaces. SO_x control processes introduce valuable byproducts into the national economy, such as sulfur, sulfuric acid, sintered iron, building materials of dolomite modified fly ash, to mention a few. Almost certainly, the program of SO_x research and development will provide solid benefits for other aspects of air pollution control. More specifically, the 10 technological area surveys of the program dealing with flue gas treatment (later to be identified as Program I) are basic and will apply broadly in control technology. Early results of work on the molten carbonate process show promise for control of nitrogen oxides as well as SO_x. Knowledge developed in process instrumentation for SO_x control techniques in the program concerning fuel availability surveys (later to be identified as Program VII) will be transferable to control techniques with other pollutants. These are but a few examples of the impact of sulfur oxides research and development on other technological areas.

H. Current Research and Development Objectives

With the requirements of the current and long-range goals of the sulfur oxides control program and subject to the technological options now available, the NCAPC has formulated one general objective. The objective is to make available a variety of control options, which will permit individual emitters to abate their pollution at minimum additional cost. The approach is to strive first for the development of relatively few control methods that economically fit large classes of sulfur oxides emitters; then, to expand the class of emitters that can economically use a control method by adapting and improving the method or by developing new methods to apply to those classes not yet accommodated. The complete research and development effort based on the above objective and approach is presented in detail in the next chapter.

Chapter II

THE FEDERAL RESEARCH AND DEVELOPMENT PROGRAM

A. Overall Program

The Federal Government is currently engaged in an aggressive program to develop economically acceptable methods to control emissions from the important sources of atmospheric pollution. The Federally sponsored work includes projects being conducted in Government agencies, industry, research institutes, and universities. Generally, the work is problem-oriented to the maximum, most projects being directed toward development of hardware and processes to control specific sources of pollution. Although work is going on for both vehicular and stationary sources, and for pollutants other than sulfur oxides (e.g., nitrogen oxides and pollutants from incineration), this document is limited to discussion of work to control the sulfur oxides segment of pollution. It presents all Federal research and development plans and programs to advance the technology for control of sulfur oxides. The plans are principally developed for the 5-year fiscal time span from 1968 through 1972.

1. Program Goals

The Federal research and development program for SO_x air pollution control consists, in large part, of projects that relate to some aspect of the problem of pollution from combustion and industrial process sources. The work is directed toward three goals:

- First, the development of processes for control of sulfur oxides from power generation. These processes include flue gas treatment, fuel desulfurization and conversion, and new combustion processes. Process development will be conducted up through large-scale prototype and demonstration studies. The objective of the work is to define the economic potential of each of the promising processes and generate design data for full-scale equipment.

- Secondly, an intensive search for new sulfur control processes having long-range potential greater than that of the "first-generation" processes.

- Finally, the development of controls for sulfur emissions from sources other than those from the combustion of fossil fuels. These sources account for roughly 30 percent of the total sulfur oxides pollution.

2. NCAPC and Other Federal Agencies Relationships

The Federal research and development program was developed from data collected from Government agencies which are either directly or indirectly concerned with control of sulfur oxides pollution. The agency most directly concerned is, of course, the National Center for Air Pollution Control. The other agencies whose research and development programs are contained in part herein, i.e., Office of Coal Research, Bureau of Mines, Tennessee Valley Authority, and the Federal Power Commission, are not primarily concerned with air pollution control. Their work, in accordance with their charters, is generally resource-oriented. For example, the OCR, using contractual research, is to develop more efficient methods of mining, preparing, and utilizing coal. The Bureau of Mines is to conserve and develop mineral resources and promote safe and healthful working conditions in the mineral industries. The research in which these agencies are engaged, however, may advance the technology of SO_x control; for this reason selected R&D efforts of these Federal agencies are included in this overall program.

3. Program Structure

The overall Federal program for development of controls for SO_x is presented as a group of nine component programs which are listed and defined in Table 3.

The first six of these programs are directed toward development of specific solutions for control problems, using experimental methods. The remaining three programs provide support for the first six.

Each of the nine programs is composed of one or more program elements. The program elements may have varying definitions dependent in part upon the nature of the programs. A program element may be defined as the development of a specific process, the study of a group of processes, or the performance of a clearly definable effort or group of efforts essential to the program. A data sheet is prepared for each program element. This element sheet contains information concerning starting and completion dates, total costs, funding organization, performing organization, project director, technical description, applicability, constraints, related R&D efforts, and required tasks.

The definition of a task, like that of a program element, is dependent in part on the nature of the program or program element. In the technical programs that are directed toward development of processes, the tasks are often conveniently definable as the steps in the development procedure which generally include some or all of the following: feasibility, laboratory, bench-scale, pilot plant, prototype plant, and demonstration plant studies. Unfortunately, the definitions of these terms are not standardized either inside or outside of the Federal Government. For supporting programs, the tasks may consist of paper studies, surveys, consulting, mathematical modeling, and so on. In such cases, a task frequently is defined by a specific project and is conveniently designated by the project title. The program element sheet contains its tasks and a time schedule for accomplishing the tasks.

Table 3

PROGRAM DESCRIPTIONS

Program	Description
I. Flue Gas Treatment	Development of processes for removing SO_x from the flue gases of combustion processes or from the waste gases or other processes.
II. Stack Meteorology	Studies of the behavior and dispersion of waste gases discharged from chimneys, and of the potential for mitigating the effects of SO_x emissions by discharging the waste gases through tall stacks.
III. Fuel Desulfurization	Development of processes for removing sulfur from fuels. Categories of processes: Desulfurization of oil Desulfurization of coal
IV. Fuel Conversion	Development of processes for conversion of coal to liquid, gaseous, or modified solid fuels. Opportunity for simultaneous desulfurization of the fuels may be afforded but is not necessarily the primary objective sought. (Conversion of oil to gaseous fuel is another potential category of this program, but is not being actively pursued.)
V. New Combustion Processes	Changes in combustion or manufacturing processes that may eliminate the release of SO_x, capture the SO_x within the process, or drastically reduce the volume of waste gas and therefore reduce the cost of subsequently collecting the SO_x.
VI. Industrial Process Control	Surveys of the technology of various industries as related to air pollution, intended to define the air pollution problems of these industries and to indicate the research and development effort necessary to find solutions for these problems and implement the R&D.

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Table 3 (Continued)

Program	Description
VII. Fuel Availability	Surveys of the availability and location of low sulfur fuels, as related to regional requirements, technology, economics, and social impacts and constraints of the production, storage, and use.
VIII. Supporting Instrumentation Development	Survey of requirements for instrumentation of SO_x control processes, determination of availability of "off-the-shelf" hardware, establishment of performance specifications, and design, development, and testing of monitoring and control equipment.
IX. Program Development, Analysis, and Evaluation	Development of in-house and consultant capabilities required to provide decision supporting studies, plans, programs, and analyses; establishment of required control systems for initiating and monitoring SO_x control R&D programs performed both in-house by contractor or by other Government agencies.

In the development of the overall SO_x R&D control program, attention is focused on the elements and tasks of the nine component programs, rather than on the variety of individual projects. Nevertheless, in the real world, the actual work to achieve objectives of a program, its elements and tasks, is conducted at the project level. The project basis is used in funding research and development contracts and delineating parts of a program, program element, or task into a specific package for investigation. A project may constitute a portion of a task, one or more complete tasks, or a complete program element. The scope of a project depends upon such factors as the availability of funds; the talents, objectives, and workloads of contractors and Federal agencies; the progress of collateral and interrelated projects; and the contracting policies of the agency involved. To show the relationship of individual projects to program objectives and to relate operational activities to planning, supplementary project data sheets follow certain of the program element sheets. The project information on the supplementary data sheets consists of project identification, costs, start and completion date, executing contractors or agencies, funding source, and explanatory remarks which amplify the intent of the project or relate and integrate it into an orderly network of events.

For a condensed overview, the SO_x control development program is outlined in Table 4. This table shows the relationship of programs, program elements, and tasks. Descriptive information on the individual programs and their elements is narrated in a subsequent section of this chapter. Each program description is followed by its detailed data sheets which were discussed in the preceding paragraphs.

4. Program Funding

Figure 2 shows the funding support for Federal sulfur oxide control R&D and related programs. Funds are depicted by funding agency and fiscal year of allocation. The last column shows that NCAPC plans to fund $255,605,000 for projects whose primary objective is SO_x control. NCAPC will utilize only a very small amount of the approximately $255.6 million for "in-house" work. The in-house spending will be for contract monitoring and some research needed for program awareness and guidance. Essentially, all NCAPC funds will (1) support contract R&D in the private sector and (2) supply funds through transfer to other Government agencies for cooperative efforts utilizing their available expertise.

Other Federal agencies (Bureau of Mines, Office of Coal Research, Tennessee Valley Authority, and Federal Power Commission) plan to fund $188,325,000, mostly for projects whose primary objective is other than SO_x control, but whose results will have an impact or collateral benefits on SO_x control. Bureau of Mines and FPC conduct their work in-house, OCR performs its work by contract, and TVA performs work largely applicable to the solving of problems closely related to its own operations.

Figure 3 arrays the funding according to programs but without regard to funding source. Both bar charts show that total program funding increases each year to FY 70; thereafter the funding tapers off.

Table 4

PROGRAM OUTLINE

Programs	Program Elements	Tasks
I. Flue Gas Treatment	A. Alkalized Alumina Process	1. Bench scale 2. Pilot plant 3. Process evaluation and prototype design 4. Prototype studies 5. Prototype (improved version)
	B. Limestone Process	1. Bench scale 2. Pilot plant 3. Prototype plant 4. Demonstration plant
	C. Molten Carbonate Process	1. Bench scale 2. Pilot plant 3. Prototype
	D. New Stack Treatment Processes	1. Exploratory and feasibility studies 2. Exploratory and supporting bench scale studies 3. Pilot plant studies
	E. Process Design and Economic Evaluations of Flue Gas Treatment Processes	1. Evaluation of processes for removal of SO_2 from flue gases 2. Conceptual design and economic evaluation of SO_2 control processes 3. Cost utilization model--control of large new power plants

Table 4 (Continued)

Program	Program Elements	Tasks
II. Stack Meteorology	A. Plume Rise and Dispersion from Tall Stacks	1. Develop hypotheses, models, instruments, and plans 2. Collect field data for test of hypotheses 3. Analyze and evaluate observations, develop conclusions
	B. Chemistry of SO_x	1. Define effluents and their chemical behavior 2. Design and construct pilot furnace 3. Conduct reactor studies 4. Publish report
III. Fuel Desulfurization	A. Desulfurization of Residual Oil	1. Exploratory and supporting studies 2. Bench scale 3. Pilot plant
	B. Desulfurization of Crude Oil	1. Exploratory and supporting studies 2. Bench scale
	C. Desulfurization of Petroleum Coke	1. Exploratory and supporting studies
	D. Desulfurization of Coal by Pyrite-Coal Process	1. Survey and analysis 2. Bench scale 3. Pilot plant 4. Prototype
	E. New Systens and Physical Methods of Producing Low Pyrite Coal	1. Feasibility and exploratory studies 2. Bench scale 3. Pilot plant
	F. New Fuel Desulfurization Processes	1. Exploratory and supporting studies 2. Bench scale 3. Pilot plant
IV. Fuel Conversion	A. Molten Salt Gasifaction	1. Feasibility and exploratory studies 2. Bench scale 3. Pilot plant

Table 4 (Continued)

Program	Program Elements	Tasks
IV. Fuel Conversion (Continued)	B. Hydrogasification	1. Design 2. Bench scale 3. Pilot plant
	C. CO_2 Acceptor Process Lignite Gasification	1. Laboratory 2. Bench scale 3. Pilot plant
	D. Gasification Optimization	1. Basic studies and reporting 2. Computer studies
	E. Fixed-Bed Gasification	1. Bench scale 2. Pilot plant
	F. Sulfur Control by Means of Coal Gasification	1. Laboratory study to trace sulfur in the gasification of coal 2. Laboratory study of the use of dolomite for removal of sulfur during gasification of coal
	G. Synthetic Pipeline Gas from Coal	1. Laboratory 2. Bench scale 3. Pilot plant 4. Commercial design
	H. Catalytic Methanation	1. Bench scale 2. Pilot plant 3. Prototype
	I. Production of Synthetic Crude Oil from Coal (GASOLINE)	1. Pilot plant 2. Surveillance and evaluation
	J. Fluidized Coking of Residual Coal to Yield Liquid and Solid Boiler Fuel (SEACOKE)	1. Laboratory

Table 4 (Continued)

Program	Program Elements	Tasks
IV. Fuel Conversion (Continued)	K. H-Coal Process	1. Bench scale 2. Pilot plant
	L. Char-Oil Energy Development (COED)	1. Laboratory and bench scale 2. Pilot plant
	M. Low-Ash Coal	1. Laboratory and bench scale 2. Pilot plant
	N. Solvent Refined Coal	1. Technical and economic evaluation
	O. Refuse as a Low-Sulfur Fuel	1. Exploratory and feasibility studies
	P. Undesignated Fuel Conversion Projects	1. Exploratory and feasibility studies 2. Laboratory and bench scale 3. Pilot plant 4. Prototype and/or demonstration
V. New Combustion Processes	A. Fluidized Bed Combustion	1. Pilot plant 2. Design of commercial boilers
	B. Coal Conversion to Electricity	1. Bench scale 2. Pilot plant
	C. Fuel Cells	1. Feasibility and laboratory studies 2. Bench scale 3. Pilot plant
	D. Undesignated New Combustion Processes	1. Feasibility studies and evaluation 2. Large-scale pilot plant 3. Prototype

Table 4 (Continued)

Program	Program Elements	Tasks
VI. Industrial Processes Control	A. Non-utility Control Processes (General)	1. Industrial surveys and control feasibility studies 2. Exploratory and supporting bench scale studies 3. Pilot plant studies 4. Prototype and demonstration studies in cooperation with industry
VII. Fuel Availability Surveys	A. Availability of Low-Sulfur Coal	1. Collect data 2. Analyze data for reserves by sulfur content and estimated delivered costs 3. Analyze data for economic and social impact in selected areas 4. Prepare report
	B. Development of Special Purpose Coals	1. Secure coal and char samples 2. Chemical, physical, and petrographic analyses 3. Coal grinding studies 4. Coal separation studies 5. Testing studies in OCR processes 6. Combustion studies 7. Evaluation and report
	C. Availability of Natural Gas as a Substitute Low-Sulfur Fuel	1. Develop an estimate of the equations for natural gas demand 2. Prepare a more comprehensive model of supply, transport, and demand of natural gas 3. Analyze thoroughly one air control region in terms of natural gas demand, etc. 4. Apply the format to other selected areas

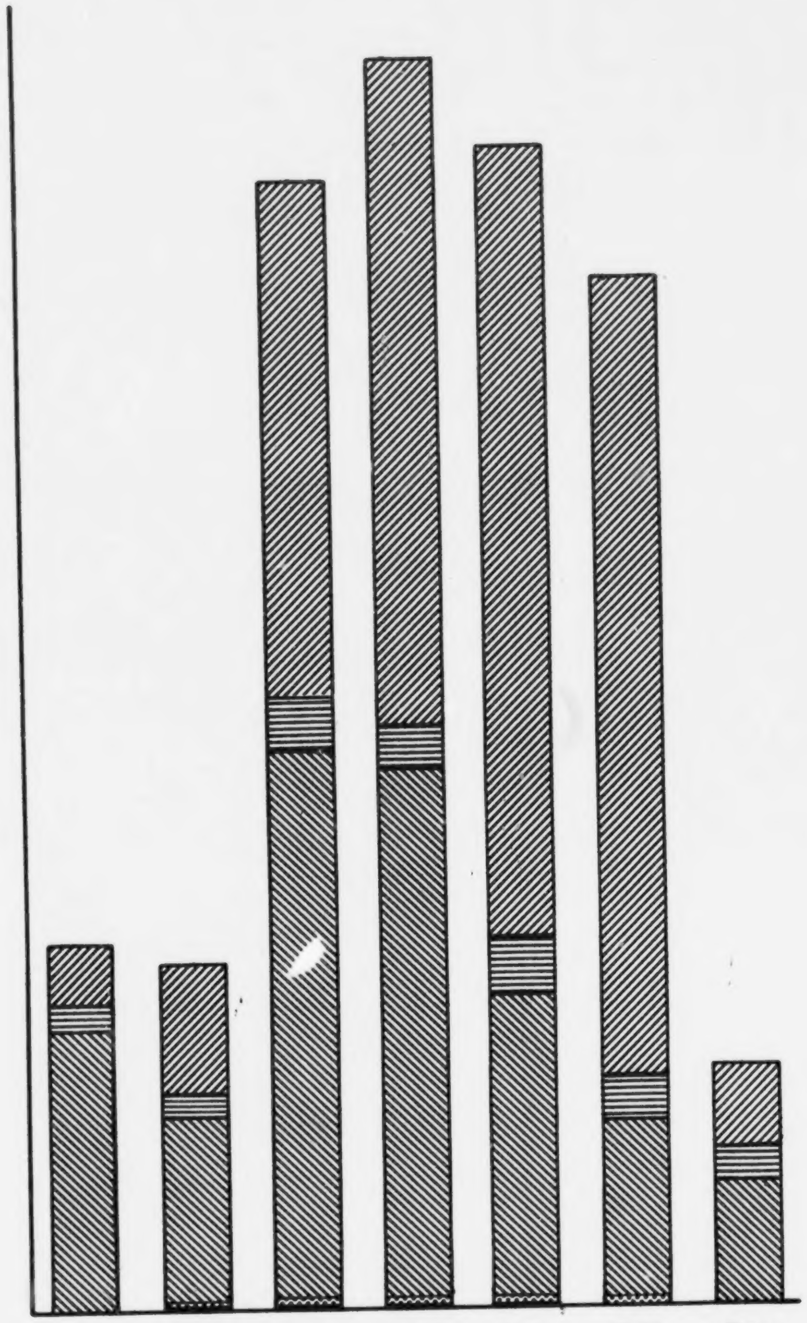
Table 4 (Continued)

Program	Program Element	Tasks
VII. Fuel Availability Surveys (Continued)	D. Technology and Availability of Liquefied Natural Gas	1. Collect data 2. Analyze data 3. Prepare report
	E. Availability of Various Grades of Oil Under Various Idealized Refining Modes	1. Develop general model 2. Develop realistic constraints and determine their effect on availability of low-sulfur oils 3. Develop summary report on availability of low-sulfur oils
	F. Undesignated Fuel Availability	1. Collect data 2. Analyze data 3. Publish report
VIII. Supporting Instrumentation Development	A. Development of Instrumentation of SO_x Control Activities	1. Development of specifications for SO_x ambient air monitoring instruments 2. Design, development, and testing of SO_x monitoring instruments
	B. Process Instrumentation and Control	1. Survey of requirements for process control 2. Survey of availability of "off-the-shelf" components 3. Design and development of specific integrated control systems
IX. Program Development, Analysis, and Evaluation	A. General Planning Studies	1. Simulation approach to air pollution abatement 2. Comprehensive program planning study for SO_x control 3. Others
	B. Program Development, Implementation, and Control	1. Program development 2. Implementation 3. Control

Figure 2

TOTAL FEDERAL PROGRAM

By Funding Agency
(Thousands of Dollars)



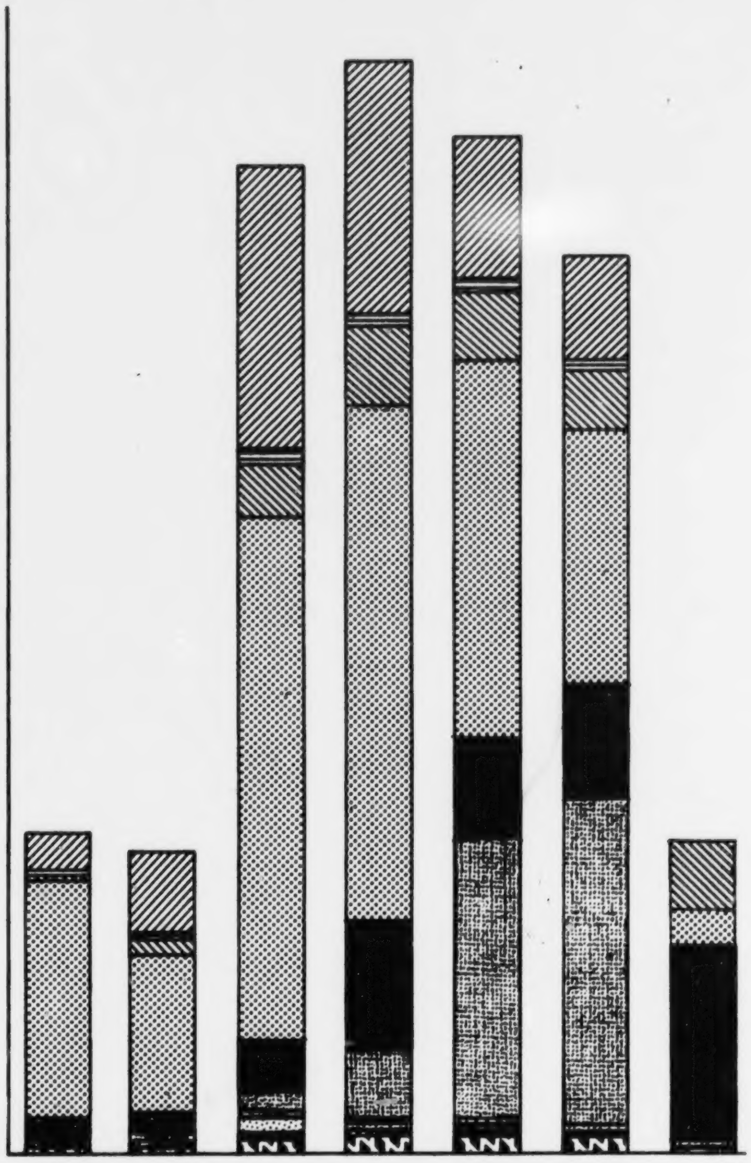
Funding Agencies

		Prior FY 68	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72	Total
▨	NCAPC	4461	9844	41700	56636	65419	65995	11550	255605
▤	BuMines	2042	1981	4009	3637	4272	3379	2450	21770
▧	OCR	21605	14602	42264	39873	23623	13890	9278	165135
░	TVA	0	150	300	300	300	300	0	1350
■	FPC	0	10	20	20	20	0	0	70
	Total	28108	26587	88293	100466	93634	83564	23278	443930

Figure 3

TOTAL FEDERAL PROGRAM

By Major Program
(Thousands of Dollars)



	Major Programs	Prior FY 68	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72	Total
▨	I. Flue Gas Treatment	3752	7493	24616	22724	12577	9520	0	80682
☰	II. Stack Meteorology	50	388	671	600	600	350	0	2659
▧	III. Fuel Desulfurization	552	1273	5411	6847	6349	5704	7100	33236
▒	IV. Fuel Conversion	20727	13519	46144	50353	35248	24540	1428	191959
■	V. New Combustion Processes	2644	1860	5835	10512	9770	10000	13700	54321
▩	VI. Industrial Process Control	0	882	1700	6150	26000	31000	0	65732
▤	VII. Fuel Availability Surveys	160	612	2316	1380	1190	1050	1050	7758
▦	VIII. Supporting Instrumentation Development	0	0	500	500	500	0	0	1500
▩	IX. Program Development, Analysis, and Evaluation	223	560	1100	1400	1400	1400	0	6083
	Totals	28108	26587	88293	100466	93634	83564	23278	443930

PROGRAM I

FLUE GAS TREATMENT

B. Program I: Flue Gas Treatment

The research and development program on flue gas treatment consists of three principal elements directed specifically to development of processes and a fourth supporting element. The first element is the development of the alkalized alumina process, a dry regenerative process for absorption of SO_x at high temperatures. The absorbent is regenerated and recycled, with the absorbed SO_x being recovered in the form of elemental sulfur. The process is expected to be applicable to large new power plants. The details of the four elements and their respective projects are shown on program element and supplemental data sheets NCAPC-1-A, B, C, D, and E, following.

1. Alkalized Alumina

Alkalized alumina is considered a good candidate for scale-up studies because it is one of the few sulfur-producing processes that is adaptable to control of large new fossil-fueled power stations. Moving the alkalized alumina program ahead at the desired rate when funding became available in 1966 required that the Government call upon immediately available industrial competence. Technical direction for the program which was then begun is provided jointly by representatives of the NCAPC and the Bureau of Mines. Non-Federal contractors include W. R. Grace, engaged in research to prepare improved sorbent materials, and AVCO Research and Development, conducting reactor studies. Central Electricity Generating Board in England is studying its own version of the alkalized alumina process, and cooperative U.S.-British studies are under consideration. Because these projects are now generating large amounts of design data, M. W. Kellogg has been retained as a prime contractor to evaluate information from all sources and perform comprehensive design studies and economic evaluations directed toward large-scale prototype and demonstration work.

The greatest single current uncertainty in the alkalized alumina process is the degree of loss of the absorbent due to attrition. The absorbent is expensive, and unless a form adequately resistant to attrition can be developed or the process modified to mitigate attrition, the loss may make the operating cost of the process unduly high.

2. Limestone Dolomite

The limestone processes under study are all interrelated in some degree. All involve injection of dry limestone or dolomite into the flue gases, either at the furnace itself or at various locations downstream of the furnace. In the various modifications of the basic process, the injected limestone is either permitted to react further in a dry reactor of some type, collected dry in a dust collector, or collected wet in a scrubber where additional reaction may take place between the SO_x and the lime or limestone dissolved in or suspended in the scrubber water. Currently, studies are being carried on at all the task levels. The limestone processes are expected to be applicable to small or intermediate-sized utility plants, and possibly to some non-utility sources of SO_2 emission. They are nonregenerative systems, with no useful recovery of the sulfur. The reacted or partly reacted limestone must be disposed of in some manner, and a part of the studies underway is devoted to finding potential useful outlets for this material.

The program to develop processes using limestone or dolomite reactants was undertaken even though variations of limestone-based processes have a considerable history of inconclusive study. A system that starts with inexpensive, readily available sorbent, utilized in a simple process not dependent upon production of chemicals as byproducts, is highly attractive, particularly for existing plants. Past efforts have been successful enough to suggest that there might be developed an economically attractive process if adequate fundamental data were provided for use in overcoming the known problems. At present, over $2 million in Federal funds have been invested in a program to optimize limestone-based processes. This NCAPC activity involves a cooperative project with Bituminous Coal Research and the Tennessee Valley Authority to evaluate about 70 different limestone-dolomite materials from different parts of the United States. By contract, Battelle Memorial Institute is studying reaction kinetics, and Babcock and Wilcox is engaged in small pilot studies of reactions of limestone-dolomite materials with sulfur oxides in flue gases from a small coal-burning furnace. Esso Research and Engineering is studying the feasibility of using limestone in a dry fluidized bed reactor, especially designed for effective contacting of gases and solids. A contract to the West Virginia Coal Research Bureau pertains to uses for the sorbent fly ash mixtures that would be produced by such limestone-based processes; this work is jointly supported by the State of West Virginia and the NCAPC. NCAPC will transfer funds to TVA to conduct large demonstration plant studies using a dry collection system for the reacted dolomite. In addition, NCAPC will contract with the private sector to conduct a large demonstration study using the wet-collection method.

3. New Process Development

The program of new-process development is aimed primarily at providing second generation processes for removing the SO_x from flue gases from the combustion of fossil fuels that contain sulfur. The need for new processes is indicated by the known economic, efficiency, and by-product limitations of the first-generation processes, such as limestone sorption or the alkalized alumina processes. Unless there is a start now to develop improved processes, the ability to economically control sulfur pollution during and beyond the 1970's will be seriously impaired. For this reason, the NCAPC is negotiating a series of investigations in which specific areas of technology will be studied in depth to generate new concepts.

This program was launched in June 1967 in a contractor's briefing meeting to outline goals. This meeting was attended by representatives of 115 industrial and research organizations, most of whom are now competing for new-process development work. Two types of contracts are being negotiated. One series will be devoted to thorough, broad surveys of presently available technology in nine areas: aqueous solution, dry metal oxide sorption, direct reduction to sulfur, inorganic liquids, inorganic solids, catalytic oxidation, organic liquids, organic solids, and physical separation. In addition to these, a tenth area has been added, focussing on fertilizer-oriented processes, which will be principally the concern of TVA. The studies will emphasize applicability to control of SO_2 emissions and will identify deficiencies in available data. The second phase of new-process development calls for unsolicited proposals. There will be support for feasibility studies or original ideas. This is seen as a challenge to the Nation's engineering resources, and hopefully many imaginative and novel concepts offering potential for sulfur pollution control will result.

As stated above, NCAPC expects to support additional feasibility studies (perhaps 10 per year) during the next 2 years. However, it is not expected that many of the proposed processes will survive beyond the stage of feasibility studies, and still others can be expected to be eliminated at the bench-scale, pilot plant, and prototype stages. Based on an anticipated rate of attrition, estimates have been made of the numbers of processes passing through each stage of development during the next 7 or 8 years and of the probable order of costs involved in developing the expected survivors through each stage. It is not yet possible to say what these processes will be, but only to indicate their probable general characteristics and applications and the general magnitude of costs in developing those that do survive each stage.

The feasibility studies cannot be continued indefinitely. With an anticipated development period of about 7 years for a given process, any new processes taken under examination after 1969 will probably not be ready for use before 1976 to 1978. By that time, the period of most critical need for such processes may be past.

A summary of the funding for the Flue Gas Treatment Program by agency and program element is shown in Figures 4 and 5, respectively. Figure 4 shows that NCAPC plans to fund a total of $76,927,000 in the area of the flue gas treatment. An inspection of program element and supplemental data sheets NCAPC 1-A, B, C, D, and E and of the grouping of shown expenditures by performing agencies or contractors reveals that NCAPC plans to contract about $26.2 million of the above funds in the private sector and transfer about $3.7 million and $8.9 million to the Bureau of Mines and TVA, respectively. In the area of new stack treatment processes, another $38 million is available for contract in the private sector or transfer to Federal agencies, depending upon comparative analysis of specific proposals. Thus, these funds cannot yet be specified at the detailed project level. At this time, they can be programmed only at the program element level.

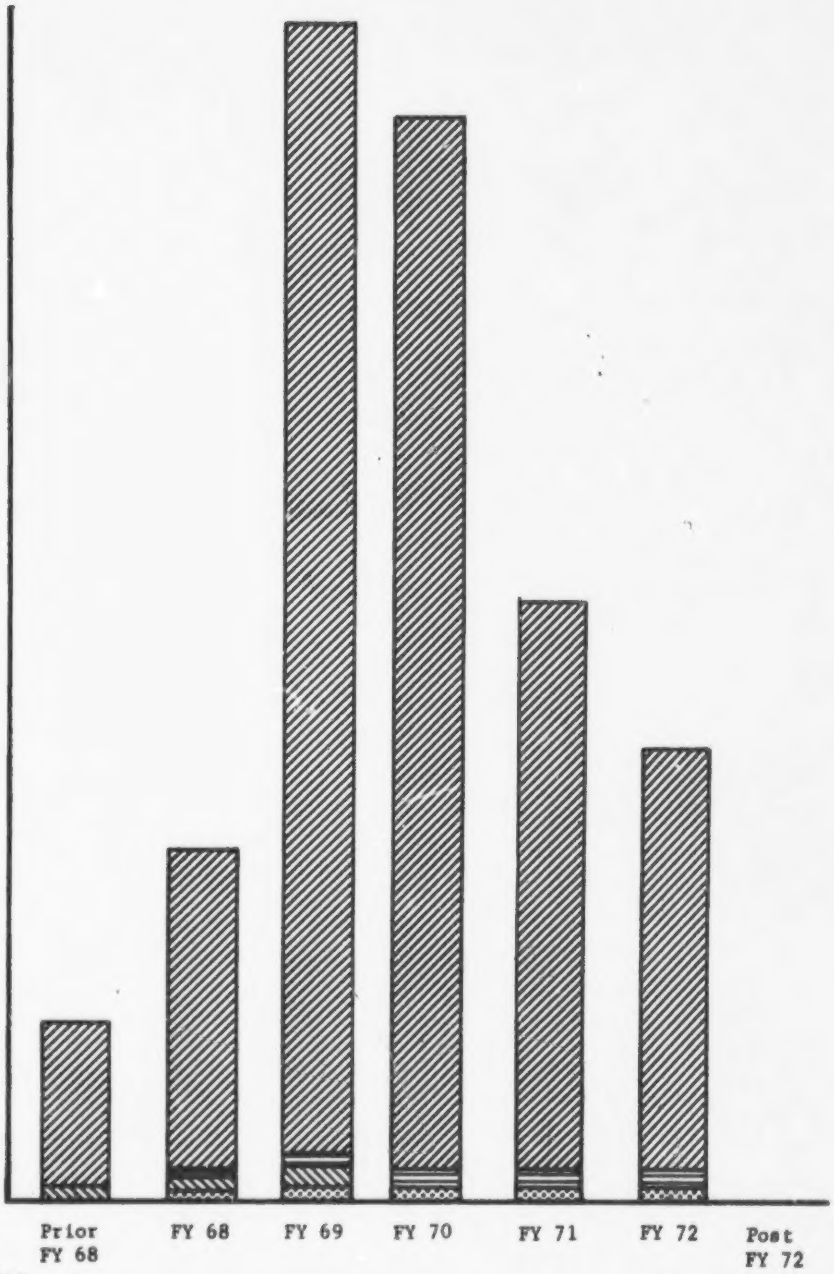
In flue gas treatment, the Bureau of Mines plans to fund a total of $1,499,000. Their funds will be utilized in kinetic and sorbent development studies in alkalized alumina, in small-scale limestone work, and in new stack gas cleaning research. The Office of Coal Research plans to fund work in dolomite addition to furnaces for the purpose of preventing fireside corrosion. This work may have collateral benefits which will accrue to the benefit of limestone injection processes. TVA plans to fund $1,350,000 for new stack treatment processes which are fertilizer-oriented and particularly well suited to the TVA systems. The funding planned by these agencies brings the total Federal program to $80,682,000.

The annual financial plan by funding source and performing organization can be seen at the bottom of the program element sheets. The funds shown for a performing organization are usually different from those shown for it under funding source. Contract negotiations and transfer of funds across Federal agency lines accounts for these differences.

Figure 4

PROGRAM I. FLUE GAS TREATMENT

By Funding Agency
(Thousands of Dollars)



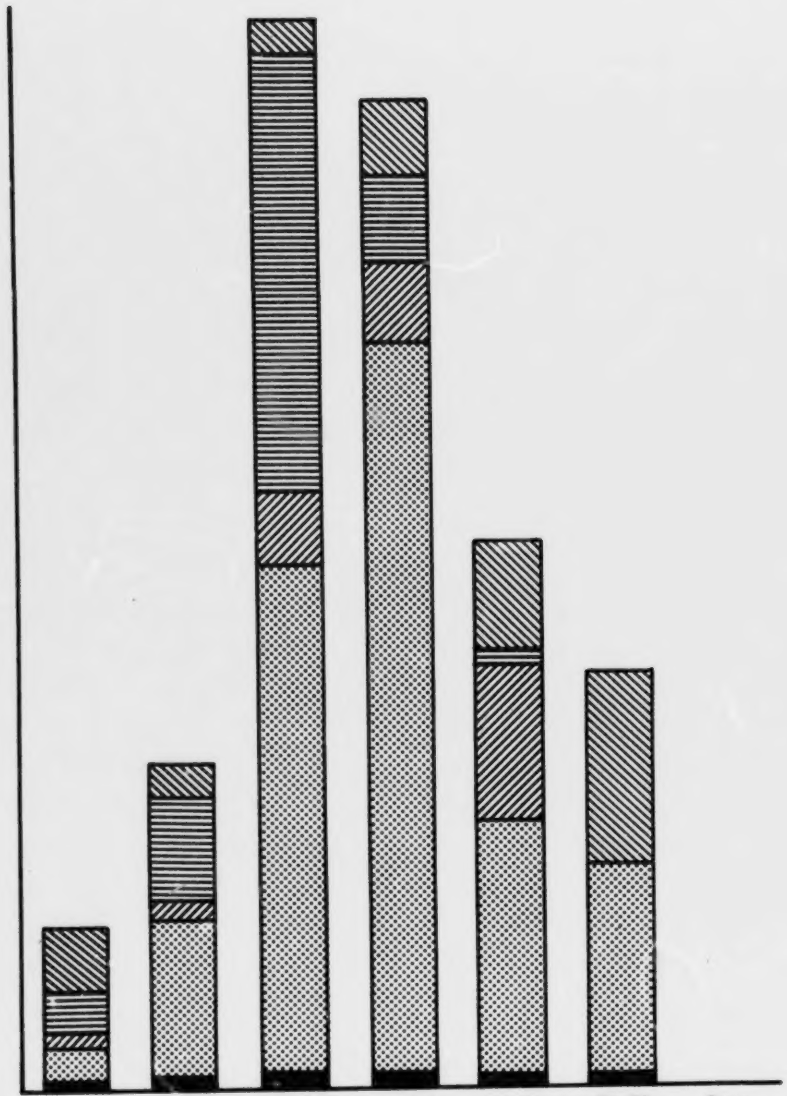
	Funding Agencies	Prior FY 68	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72	Total
▨	NCAPC	3485	6895	23649	22039	11944	8915	0	76927
▤	BuMines	0	209	267	385	333	305	0	1499
▧	OCR	267	239	400	0	0	0	0	906
░	TVA	0	150	300	300	300	300	0	1350
■	FPC	0	0	0	0	0	0	0	0
	Total	3752	7493	24616	22724	12577	9520	0	80682

321-780 O - 68 - 5

Figure 5

PROGRAM I. FLUE GAS TREATMENT

By Program Element
(Thousands of Dollars)



Program Elements

		Prior FY 68	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72	Total	NCAPC Share of Total
▧	A. Alkalized Alumina Process	1485	789	845	1752	2532	4380	0	11783	11309
▤	B. Limestone Processes	960	2378	10034	1964	330	0	0	15666	14502
▨	C. Molten Carbonate Processes	321	440	1684	1875	3575	0	0	7895	7895
░	D. New Stack Treatment Processes	876	3616	11708	16823	5880	4880	0	43783	41666
■	E. Process Design and Economic Evaluation of Flue Gas Treatment Processes	110	270	345	310	260	260	0	1555	1555
	Total	3752	7493	24616	22724	12577	9520	0	80682	76927

SULFUR OXIDE CONTROL R&D AND RELATED PROGRAMS

Program I FLUE GAS TREATMENT	**Program Element** ALKALIZED ALUMINA PROCESS	**Identification/Contract No.** NCAPC-I-A

Initiation date July 1956	**Est. completion date** 1972	**1st decision review**	**2nd decision review**	**Initial contract amount**	**Estimated total costs** $ 11,783,000

Bureau responsible National Center for Air Pollution Control	**Sub organization** CONTECH	**Project director** R. P. Hangerbrauck
Contractor or in-house organization performing work Various	**Location of work** Various	

Technical description

The SO_2 is absorbed at elevated temperatures (600° F. or higher) by a solid absorbent composed essentially of alumina and sodium carbonate. The absorbent is contained in some type of reactor through which the flue gas flows. The spent absorbent is regenerated by reaction with hydrogen or producer gas, and recycled to the reactor. The regeneration reaction produces hydrogen sulfide, which is in turn converted to elemental sulfur in a Claus-process plant.

Utility/applicability

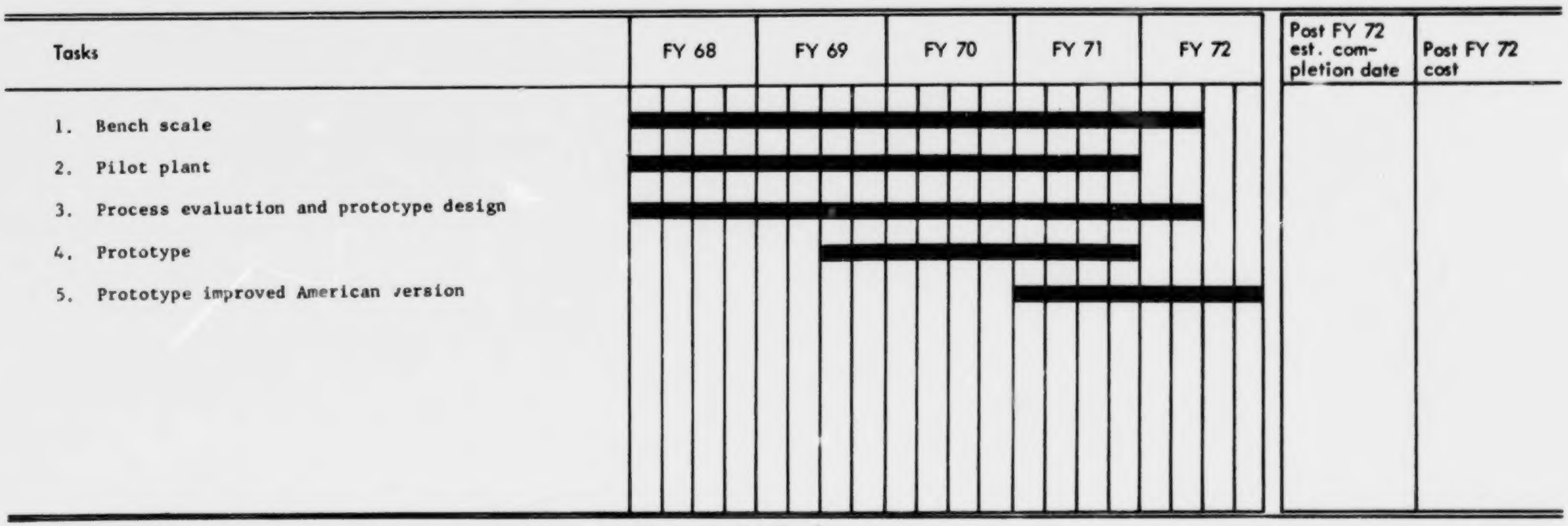
The alkalized alumina process will be adaptable to large new power plants in which the SO_2 removal system can be incorporated into the power plant design.

Constraints to successful/on time completion

The alkalized alumina sorbent is subject to losses by attrition. Since the sorbent is expensive, operating costs will be high unless an attrition resistant sorbent or a low attrition rate system is developed.

Other related or parallel R&D efforts

Other new cyclic absorption systems are now in the preliminary stages of development. These systems will produce sulfuric acid, liquid sulfur dioxide, or elemental sulfur as by-products.



1. Bench scale
2. Pilot plant
3. Process evaluation and prototype design
4. Prototype
5. Prototype improved American version

Funding--Obligated & estimated obligations required for future (thousands of dollars)

Fund source(s)		Total prior years	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 cost	Total cost
● Agency	NCAPC	1485	696	745	1649	2429	4305		11309
● Agency	Bureau of Mines	0	93	100	103	103	75		474
Total		1485	789	845	1752	2532	4380		11783
Program element performed by:									
● Agency	Bureau of Mines	942	453	575	582	582	180		3314
● Contractors	Various	543	336	270	1170	1950	4200		8469
● Other									
Total		1485	789	845	1752	2532	4380		11783

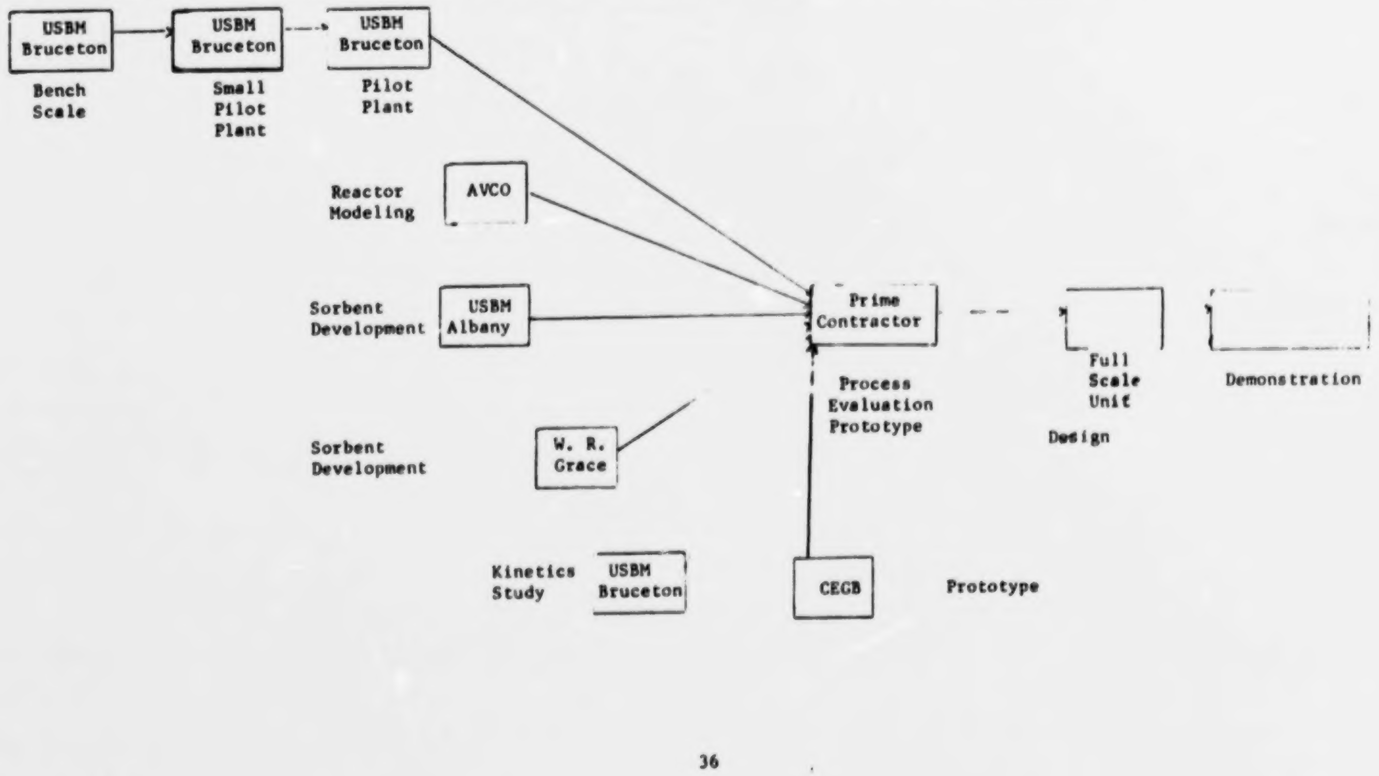
SULFUR OXIDE CONTROL R&D AND RELATED PROGRAMS

Program I	**Program Element**	**Identification/Contract No.**
FLUE GAS TREATMENT	ALKALIZED ALUMINA PROCESS	NCAPC-I-A

Supplementary data and comments The projects which make up this program element, their task status, contractor, and other pertinent data are shown below.

Project	Task Status	Executing Contractor or Agency	Funding Source and Amount	Date		Remarks
				Start	Complete	
Mechanisms and Kinetics	1	Bureau of Mines	NCAPC ($214,000) BuMines ($219,000)	1967	Indef	Reaction rate studies of the sorption and regeneration steps
Sorbent Development and Testing	1	W. R. Grace and Bureau of Mines	NCAPC ($803,000) BuMines ($255,000)	1967	1972	W.R. Grace and BuMines are working separately on improving the physical properties and reactivity of alkalized alumina catalyst investigating the fate of chlorine in coal combustion on activity of alkalized alumina catalyst
Reactor Modeling	3	AVCO	NCAPC $394,000	1967	1970	Mathematical model building of various types of reactors, generators, and catalyst transport processes. Various alkalized alumina systems modeling to support optimum design of prototype plant
Process Evaluation and Conceptual Design and Improved Prototype Design	3	M. W. Kellogg	NCAPC $966,000	1967	1972	Will take all current data on alkalized alumina and develop preliminary designs. Will specify where more pilot plant data is needed as result of preliminary design. Finally, will develop improved American prototype design based on pilot plant and CEGB prototype studies

The relationships of the Alkalized Alumina Program Element tasks and projects are shown graphically below.


USBM Bruceton
Bench Scale
USBM Bruceton
Small Pilot Plant
USBM Bruceton
Pilot Plant
Reactor Modeling
AVCO
Sorbent Development
USBM Albany
Sorbent Development
W. R. Grace
Kinetics Study
USBM Bruceton
Prime Contractor
Process Evaluation Prototype
CEGB
Prototype
Full Scale Unit
Design
Demonstration

SULFUR OXIDE CONTROL R&D AND RELATED PROGRAMS

Program I FLUE GAS TREATMENT	**Program Element** LIMESTONE PROCESSES	**Identification/Contract No.** NCAPC-I-B

Initiation date January 1962	**Est. completion date** March 1971	**1st decision review**	**2nd decision review**	**Initial contract amount**	**Estimated total costs** $ 15,666,000

Bureau responsible National Center for Air Pollution Control	**Sub organization** CONTECH	**Project director** R. Harrington
Contractor or in-house organization performing work Various	**Location of work** Various	

Technical description

The limestone processes for removal of SO_2 from flue gases fall into two subcategories: (1) Dry limestone or dolomite is introduced as a mixture with the fuel or is injected directly into the furnace where it reacts with the SO_2; it is then collected dry along with the fly ash. Alternatively, the limestone or dolomite may be used in a dry reactor, such as a fluidized bed. (2) Dry limestone or dolomite is injected into the furnace, then collected in a wet scrubber that removes the fly ash from the flue gas. In the scrubber the limestone or dolomite has a second opportunity to react with the SO_2 remaining in the flue gas. The sulfur is not recovered for use.

Utility/applicability

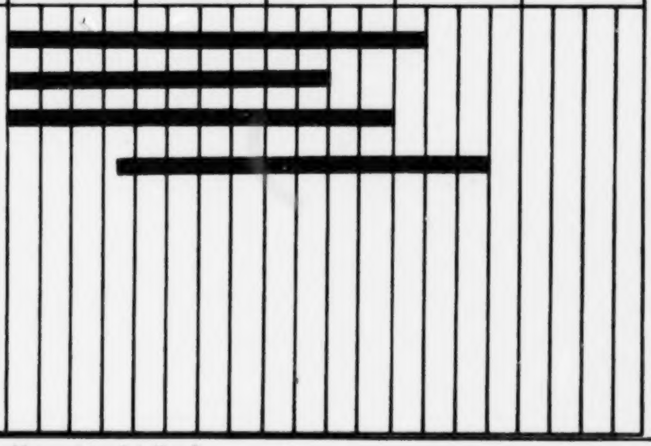
The limestone processes are adaptable to existing small- to intermediate-sized power generating plants in which the more complex cyclic SO_2 removal and recovery systems are uneconomic.

Constraints to successful/on time completion

Other related or parallel R&D efforts

The limestone processes are the only ones currently aimed at existing small- to intermediate-sized plants.

Tasks	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 est. completion date	Post FY 72 cost
1. Bench scale							
2. Pilot plant							
3. Prototype plant							
4. Demonstration plant							



Funding--Obligated & estimated obligations required for future (thousands of dollars)

Fund source(s)	Total prior years	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 cost	Total cost
● Agency NCAPC	693	2099	9525	1855	330			14502
● Agency OCR Bureau of Mines	267 0	239 40	400 109	0 109	0 0			900 258
Total	960	2378	10034	1964	330			15660
Program element performed by:								
● Agency OCR	267	239	400	0	0			906
● Agency Bureau of Mines TVA	 36	40 1468	109 4575	109 1575	 200			258 7854
● Contractor	657	631	4950	280	130			6648
Total	960	2378	10034	1964	330			15666

SULFUR OXIDE CONTROL R&D AND RELATED PROGRAMS

Program I	Program Element	Identification/Contract No.
FLUE GAS TREATMENT	LIMESTONE PROCESSES	NCAPC-I-B

Supplementary data and comments

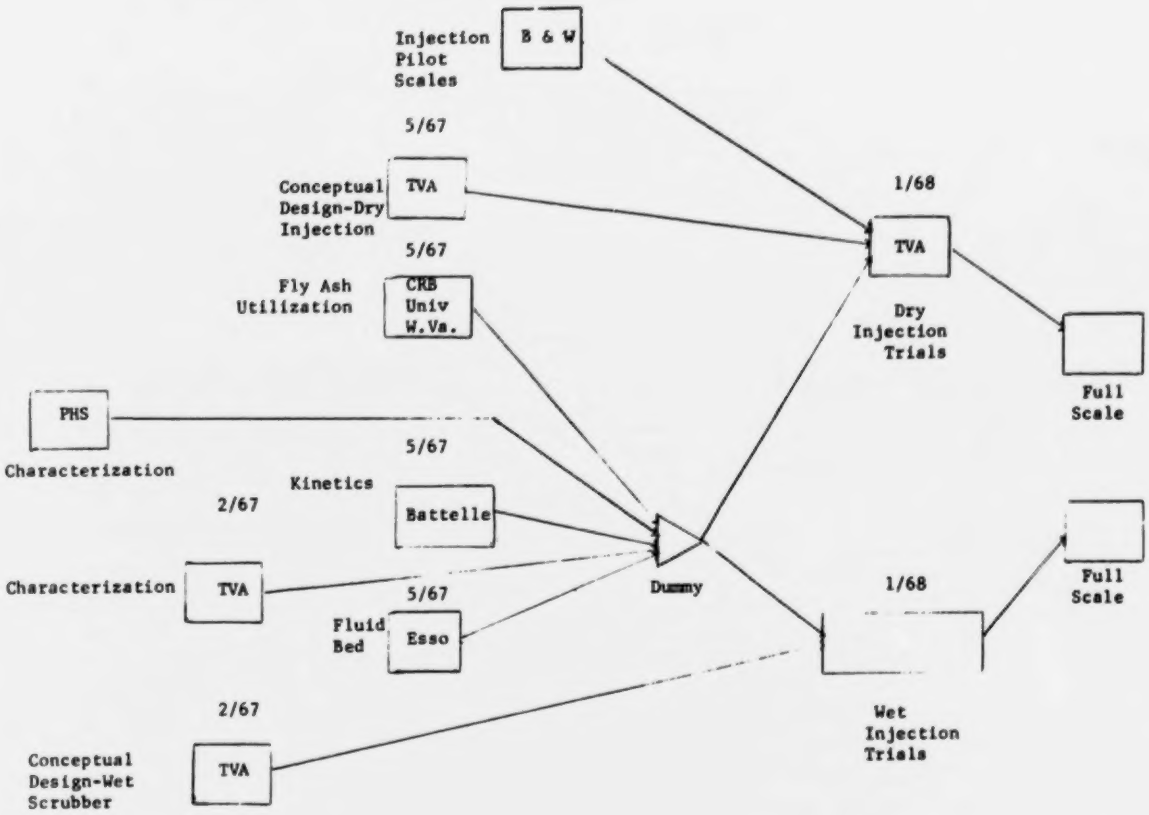
This element consists of the following projects.

Project	Task Status	Executing Contractor or Agency	Funding Source and Amount	Date		Remarks
				Start	Complete	
Effectiveness of U.S. Limestone Materials for Sulfur Collection	1	NCAPC	NCAPC $595,000	1966	1971	Absorptive capacity and reaction rates of U.S. solid alkaline materials with sulfur oxides
Reaction Kinetics of Sulfur Oxide with Limestone	1	Battelle	NCAPC $486,000	1967	1969	Extension of above project to screen samples and determine relative reactivities
Utilization of Fly Ash Modified by SO_2 Removal Additives	1	W. Virginia University	NCAPC $617,000	1967	1969	Development of useful products for fly ash modified by SO_2 removal additives
Services Contract for Physical Properties Measurements	1	American Instrument	NCAPC $55,000	1967	1969	Measures surface area, pore volume distribution and solids density of limestones and dolomites screened above
Effects of Limestone Physical Properties on SO_2 Reaction Kinetics	1	TVA	NCAPC $254,000	1967	1970	Effect of rates of calcination of limestone and dolomite on their physical properties and reactivities with SO_x
Reaction of SO_2 in Flue Gas with Limestone in a Fluidized Bed	2	ESSO Research & Engineering	NCAPC $491,000	1967	1969	Study of alternative method of contacting flue gas in limestone or dolomite
Pilot Plant Evaluation of Limestone-Dolomite Injection	2	Babcock & Wilcox	NCAPC $188,000	1967	1969	Variable study of limestone or dolomite injection in a pilot plant furnace and screening of 50 materials using optimum conditions
Limestone Additive-Studies in a Pilot Plant Furnace	2	BuMines	BuMines	1968	1970	Variable study of limestone or dolomite injected into small-scale furnace. (Not coordinated with project immediately above. Starts and finishes later. Appears to duplicate.)
Fabric Filter as a Contractor of SO_x in Flue Gas	2	Air Preheater Corp.	NCAPC $106,000	1968	1968	Evaluate fabric filters as a contactor for SO_x removal with a finely powdered solid sorbent
Limestone-Wet Scrubber Prototype	3	Unknown	NCAPC $1,610,000	1968	1969	Determine the technical and economic feasibility of limestone injection with wet scrubbing on a utility boiler
Limestone Process with Dry Reactor	3	Unknown	NCAPC $2,500,000	1969	1970	Determine technical and economic feasibility of removing SO_x from flue gas using a dry reactor
Limestone Injection with Collection by Electrostatic Precipitator	4	TVA	NCAPC $5,100,000	1967	1971	Demonstration of dry limestone injection and collection at two TVA boiler plants
Limestone Injection with Collection by Wet Scrubber	4	Unknown	NCAPC $2,500,000	1969	1971	Demonstration of limestone injection with wet-lime scrubber for collection
Prevention of Fireside Boiler Tube Corrosion by Addition of Dolomite to Coal	4	Combustion Engineering	Office of Coal Research $906,000	1965	1969	Determine amount of dolomitic materials that simultaneously reduce sulfur dioxide emission and reduce boiler tube corrosion

Program I	Program Element	Identification/Contract No.
FLUE GAS TREATMENT	LIMESTONE PROCESSES	NCAPC-I-B

Supplementary data and comments (continued)

The relationships of the Limestone Processes Program are shown graphically below.


Injection Pilot Scales
B & W
5/67
Conceptual Design-Dry Injection
TVA
5/67
Fly Ash Utilization
CRB Univ W.Va.
PHS
Characterization
5/67
Kinetics
Battelle
2/67
Characterization
TVA
5/67
Fluid Bed
Esso
2/67
Conceptual Design-Wet Scrubber
TVA
Dummy
1/68
TVA
Dry Injection Trials
Full Scale
1/68
Wet Injection Trials
Full Scale

SULFUR OXIDE CONTROL R&D AND RELATED PROGRAMS

Program I FLUE GAS TREATMENT	**Program Element** MOLTEN CARBONATE PROCESS	**Identification/Contract No.** NCAPC-I-C

Initiation date July 1967	**Est. completion date** June 1972	**1st decision review** June 1968	**2nd decision review** June 1969	**Initial contract amount** $321,000	**Estimated total costs** $7,895,000

Bureau responsible National Center for Air Pollution Control	**Sub organization** CONTECH	**Project director** E. D. Margolin
Contractor or in-house organization performing work Atomics International Division	**Location of work** Canoga Park, California	

Technical description

The flue gas is contacted with a molten eutectic mixture of alkali-metal carbonates at 800°-900° F. The SO_2 is absorbed by the molten carbonates, forming sulfites. The spent carbonate absorbent containing the sulfites is regenerated by contacting with hydrogen or with producer gas (a mixture of hydrogen and carbon monoxide), so that the sulfites are reduced to hydrogen sulfide. The regenerated carbonate mixture is recycled to the absorption step. The hydrogen sulfide is converted to elemental sulfur by the Claus process.

Utility/applicability

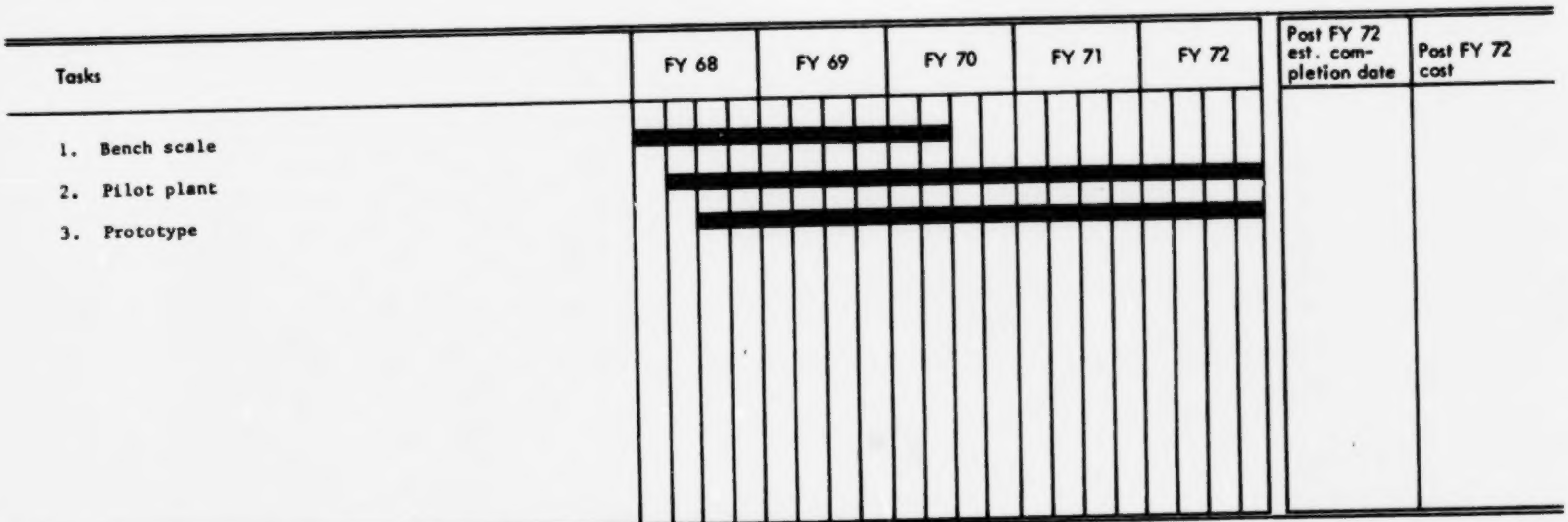
The process will be applicable to new power plants (small and large) and possibly to some other sources, such as smelters. It will probably not be practical for application to existing power plants. It is anticipated that the system, if successful, will have lower capital costs than the alkalized alumina process, and will not suffer the sorbent losses that are associated with a solid sorbent.

Constraints to successful/on time completion

There may be difficulties in developing an adequate technique for reducing the sulfites to hydrogen sulfide, and in obtaining construction materials resistant to corrosion by the molten salts.

Other related or parallel R&D efforts

Applicability of Inorganic Liquids to the Development of New Processes for Removing SO_2 from Flue Gases (PH-86-67-Neg. 135(4))



Funding--Obligated & estimated obligations required for future (thousands of dollars)

Fund source(s)	Total prior years	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 cost	Total cost
● Agency NCAPC	321	440	1684	1875	3575			7895
● Agency								
Total	321	440	1684	1875	3575			7895
Program element performed by:								
● Agency								
● Contractor Atomics International Div.	321	440	1684	1875	3575			7895
● Other								
Total	321	440	1684	1875	3575			7895

SULFUR OXIDE CONTROL R&D AND RELATED PROGRAMS

Program I FLUE GAS TREATMENT	Program Element NEW STACK TREATMENT PROCESSES				Identification/Contract No. NCAPC-I-D
Initiation date July 1967	Est. completion date Various	1st decision review	2nd decision review	Initial contract amount	Estimated total costs $43,783,000
Bureau responsible National Center for Air Pollution Control		Sub organization CONTECH		Project director E. D. Margolin	
Contractor or in-house organization performing work NCAPC, Bureau of Mines, TVA, Various Contractors		Location of work Various			

Technical description

The program consists of a series of survey projects covering ten areas of approach to means of removing SO_2 from flue gases. The surveys will review the state of the art, including literature searching, supplementary laboratory experimentation, preliminary conceptual design of promising new processes, and economic analyses of the processes. The ten areas are: (1) Aqueous Solutions, (2) Dry Metal Oxides, (3) Catalytic Oxidation, (4) Inorganic Liquids, (5) Organic Liquids, (6) Inorganic Solids Other than Oxides, (7) Organic Solids, (8) Direct Reduction to Sulfur, (9) Physical Methods, (10) Fertilizer Oriented Processes (TVA only). These studies may proceed through each of the four tasks shown below, although this is unlikely. At each task completion, a review, analysis, and decision to proceed or cancel will be made. The amounts for each task are estimated requirements for each year without regard to a specific area. The fall-out rate from task to task is expected to be (1) 15:5, (2) 5:2; (3) 2:1, (4) 1:1. The amounts in a specific area are actual known values to a decision point. See following page for additional information on these studies which have already been specified. Other studies will be specified in the future. Funding for these is provided.

Utility/applicability

The projects will provide data for the evaluation of specific proposals in the various process areas. They may reveal some fruitful avenues for development of new or improved processes.

Constraints to successful/on time completion

Other related or parallel R&D efforts

The ten study areas embrace all possible approaches to flue gas treatment.

Tasks	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 est. completion date	Post FY 72 cost
1. Exploratory and feasibility studies	■	■	■	■	■		
2. Exploratory and supporting bench scale studies		■	■				
3. Pilot plant studies			■	■	■		
4. Prototype (FY 74-75) and/or demonstration (FY 76-80)							
(Note: See details on following page)						FY 80	Unknown

Funding--Obligated & estimated obligations required for future (thousands of dollars)

Fund source(s)		Total prior years	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 cost	Total cost
● Agency	NCAPC	876	3390	11350	16350	5350	4350		41666
● Agency	Bureau of Mines TVA	0 0	76 150	58 300	173 300	230 300	230 300		767 1350
	Total	876	3616	11708	16823	5880	4880		43783
Program element performed by:									
● Agency	NCAPC *	0	2033	11000	16000	5000	4000		38033
● Agency	Bureau of Mines TVA	30 0	216 150	158 300	273 300	330 300	330 300		1337 1350
● Contractor	Various	846	1217	250	250	250	250		3063
	Total	876	3616	11708	16823	5880	4880		43783

* Funds are available for contract or transfer to agency dependent upon comparative analysis of proposals in specific areas.

SULFUR OXIDE CONTROL R&D AND RELATED PROGRAMS

Program I	Program Element	Identification/Contract No.
FLUE GAS TREATMENT	NEW STACK TREATMENT PROCESSES	NCAPC-I-D

Supplementary data and comments

Tasks in this program element involve the following.

1. Task I - Exploratory and Feasibility Studies - Consists of a series of survey projects to review the state of the art, including literature searching, supplementary laboratory experimentation, preliminary conceptual design of promising new processes, and economic analyses of the processes.

2. Task II - Exploratory and Supporting Bench Scale Studies - Investigation on a bench scale of selected new processes for removal of SO_2 from flue gases. The processes (perhaps 18 to 20 in number) will be selected from those showing adequate promise in exploratory and feasibility studies previously carried out in laboratory or preliminary bench-scale work.

3. Task III - Pilot Plant Studies - Design, construction and operation of pilot plants of selected new processes for removal of SO_2 from flue gases. The processes will be selected from those that have shown adequate promise in bench-scale studies. They are expected to include four for use in large utility plants, two producing sulfuric acid by-product, and two, elemental sulfur. There will also be two processes for small emission sources, and six processes for non-combustion sources, such as smelters or sulfuric acid plants.

The composition, funding, timetable, and task status of each of already specified studies in the ten areas are shown below:

Area and Project	Task Status	Executing Contractor or Agency	Funding Source and Amount	Date Start	Date Complete	Remarks
1. Dry Metal Oxides						
a. Applicability of Metal Oxides to Development of New Processes for Removing SO_x from the Gas	1	TRACOR	NCAPC $208,000	Jan 68	May 69	
b. Manganese Oxide Process for SO_2 Control	2	BuMines	NCAPC 70,000 BuMines 18,000	July 66	Indef	Japanese have full-scale process in operation. Definite improvements should be shown before scale-up.
c. Exploratory Studies and Larger Scale Tests on Selected Absorbents	2	BuMines	NCAPC 1,750,000	1967	1975	
2. Aqueous Solution Scrubbing						
a. Applicability of Aqueous Solutions to Development of New Processes for Removing SO_2 from Flue Gases	1	Aerojet-General	NCAPC 254,000	Jan 68	Apr 69	
3. Catalytic Oxidation						
a. Applicability of Catalytic Oxidation to Development of New Processes for Removing SO_2 from Flue Gases	1	Monsanto Res.	NCAPC 257,000	Jan 68	Jan 69	
b. Catalytic Oxidation of SO_2 with Nitrogen Oxide	2	Tyco	NCAPC 42,000	Jan 68	Jul 68	
4. Inorganic Liquids						
a. Applicability of Inorganic Liquids to Development of New Processes for Removing SO_2 from Flue Gases	1	MSA Research Corp & Singmaster & Breyer	NCAPC 65,000	Jan 68	Sep 68	
5. Organic Liquids						
a. Applicability of Organic Liquids to Development of New Processes for Removing SO_2 from Flue Gases	1	Not determined	NCAPC 110,000	FY 68		
b. High Temperature Amine Sorbents for SO_2 Control	1	A.D.Little	NCAPC 50,000	Jan 68	Mar 68	
6. Inorganic Solids						
a. Applicability of Inorganic Solids Other than Oxides to Development of New Processes for Removing SO_2 from Flue Gases	1	Not determined	NCAPC 150,000	FY 68		
7. Organic Solids						
a. Applicability of Organic Solid Sorption to Development of Processes for Removing SO_2 from Flue Gases	1	Not determined	NCAPC 150,000	FY 68		
b. Development of Regenerative Fibers for Removing SO_2 from Flue Gases	2	Uniroyal	NCAPC 40,000	Jan 68	Jul 68	
c. Teller Chromatographic Process	2	BuMines	BuMines 749,000	1967	1973	
8. Direct Reduction to Sulfur						
a. Applicability of Direct Reduction to Sulfur to Development of New Processes for Removing SO_2 from Flue Gases	1	Not determined	NCAPC 150,000	FY 68		
b. Process to Reduce SO_2 to S by Sulfide Reduction	1	Princeton Chemical	NCAPC 84,000	Oct 67	Jul 68	
9. Physical Methods						
a. Applicability of Physical Methods of Separation to Development of New Processes for Removing SO_2 from Flue Gases	1	Not determined	NCAPC 150,000	FY 68		
b. Process for Removal of SO_2 from Flue Gases by Fractional Permeation thru Immobilized Liquid Membranes	2	General Electric	NCAPC 103,000	Jan 68	Feb 69	
10. Fertilizer Oriented Processes	1	TVA	TVA 1,350 (to FY 72)	Jul 67	Indef	

SULFUR OXIDE CONTROL R&D AND RELATED PROGRAMS

Program I FLUE GAS TREATMENT	**Program Element** PROCESS DESIGN AND ECONOMIC EVALUATION OF FLUE GAS TREATMENT PROCESSES	**Identification/Contract No.** NCAPC-I-E

Initiation date Various	**Est. completion date** Indefinite	**1st decision review**	**2nd decision review**	**Initial contract amount**	**Estimated total costs** $ 1,555,000

Bureau responsible National Center for Air Pollution Control	**Sub organization** CONTECH	**Project director** Various
Contractor or in-house organization performing work Various	**Location of work** Various	

Technical description

The program element consists of various conceptual design and economic analysis projects carried out in support of the flue gas treatment program.

Utility/applicability

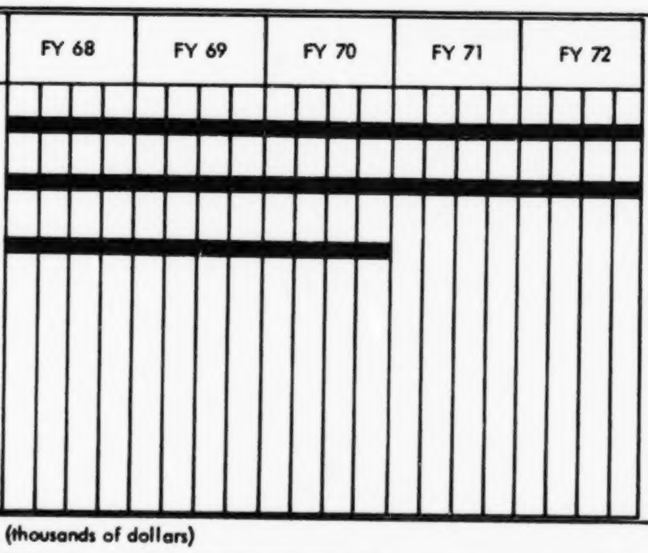
The studies provide the detailed estimates necessary for the evaluation of various competitive flue gas treatment processes at different stages of development.

Constraints to successful/on time completion

Other related or parallel R&D efforts

Tasks

1. Evaluation of processes for removal of SO_2 from flue gases
2. Conceptual design and economic evaluation of SO_2 control processes
3. Cost-utilization model--control of large new power plants



Post FY 72 est. completion date	Post FY 72 cost

Funding--Obligated & estimated obligations required for future (thousands of dollars)

Fund source(s)	Total prior years	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 cost	Total cost
● Agency NCAPC	110	270	345	310	260	260		1555
● Agency								
Total	110	270	345	310	260	260		1555
Program element performed by:								
● Agency Bureau of Mines	55	10	10	10	10	10		105
● Agency TVA	55	225	250	250	250	250		1280
● Contractor Battelle	0	35	85	50	0	0		170
Total	110	270	345	310	260	260		1555

PROGRAM II

STACK METEOROLOGY

C. Program II: Stack Meteorology

The potentials and limitations of dispersion of flue gases from tall stacks as a method of reducing ground level concentrations of sulfur oxide are only partly known. In fact, there are many unanswered questions concerning the chemical behavior of the flue gases themselves after they leave the stack. Techniques are also inadequate for predicting dispersion of gases from the very large power plant complexes now being constructed or planned.

The NCAPC program, therefore, contains two elements. The first element is devoted to determining the rise, transport, and dispersion of effluent from large, very tall stacks. Out of this research being conducted in conjunction with the TVA, accurate equations will be developed to appraise the potential ground-level pollution from large fossil fuel power plants in various topographical and meteorological regimes.

The second element of research involves the chemistry of SO_x in plumes. This undertaking was started in FY 68 and is being conducted by the Geophysical Corporation of America under NCAPC direction. However, the funding is a joint Government and industry arrangement. For both FY 68 and 69, the Edison Electric Institute, the Bituminous Coal Research Institute, and the American Petroleum Institute have underwritten a substantial part of these studies.

Though not included as a program element, it should be noted that TVA has, since the 1950's, conducted studies of the meteorological conditions around power plants using tall stacks. This work was concentrated in the TVA network to locations most conducive to raising SO_x concentrations to critical levels. The purpose of these studies continues to be the development of a meteorological prediction model which would lead to a feedback system for controlling outputs of fossil fuel power plants.

The total funding for the stack meteorology program amounts to $2,659,000, all of which is funded by NCAPC directly for SO_x control. The distribution of this amount by program elements and fiscal year is shown in Figure 6. The detailed data for the program elements follows the table. The program element sheets show the distribution of funds by fund source and performing organization.

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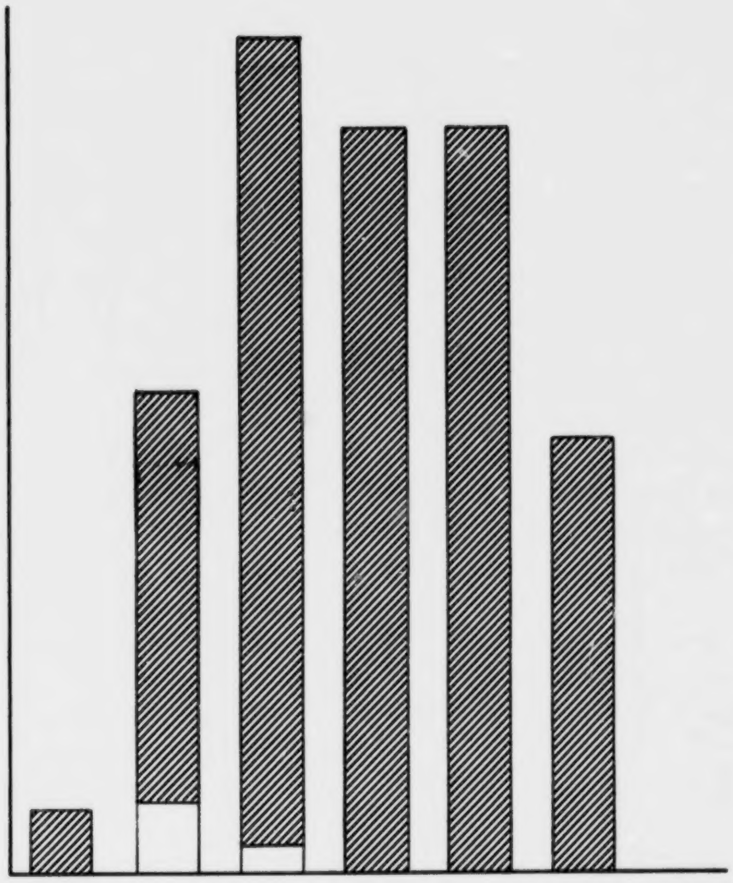
Figure 6

PROGRAM II. STACK METEOROLOGY

By Program Element*
(Thousands of Dollars)



	Program Element	Prior FY 68	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72	Total
▨	A. Plume Rise & Dispersion from Tall Stacks	50	330	650	600	600	350	0	2580
☐	B. Fate of SO_x	0	58	21	0	0	0	0	79
	Total	50	388	671	600	600	350	0	2659

*All funds provided by NCAPC.

SULFUR OXIDE CONTROL R&D AND RELATED PROGRAMS

Program II STACK METEOROLOGY	**Program Element** PLUME RISE & DISPERSION FROM TALL STACKS	**Identification/Contract No.** NCAPC-II-A

Initiation date	**Est. completion date**	**1st decision review**	**2nd decision review**	**Initial contract amount**	**Estimated total costs**
July 1967	June 1972	June 1968		$ 330,000	$ 2,580,000

Bureau responsible	**Sub organization**	**Project director**
National Center for Air Pollution Control	Meteorology	L. E. Niemeyer

Contractor or in-house organization performing work	**Location of work**
	Indiana, Pennsylvania

Technical description

The project will evaluate the effects of sulfur compounds and other effluents from a large power plant complex on receptors in region of the installation; develop and validate transport and diffusion models giving expected ground-level concentrations of these effluents; and measure the magnitude, frequency, and spatial distribution of the ground-level pollutant concentrations, singly and in combination, and compare the observed data with theoretical predictions.

Utility/applicability

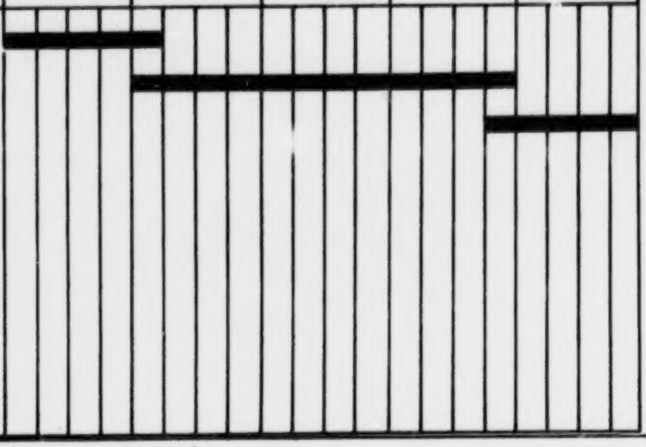
The effects of large power plants on the ecology will be known. Accurate equations to appraise the potential ground-level pollution from fossil fuel-power plants will be available for planning the installation and control of power plants in the 1-2000 mw range.

Constraints to successful/on time completion

Other related or parallel R&D efforts

Tasks	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 est. completion date	Post FY 72 cost

1. Develop hypotheses, models, instruments, and plans
2. Collect field data for test of hypothesis
3. Analyze and evaluate observations, develop conclusion



Funding--Obligated & estimated obligations required for future (thousands of dollars)

Fund source(s)		Total prior years	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 cost	Total cost
● Agency	NCAPC	50	330	650	600	600	350		2580
● Agency									
	Total	50	330	650	600	600	350		2580
Program element performed by:									
● Agency	NCAPC	0	250	400	300	300	250		1500
● Agency	TVA ESSA	50 0	30 0	80 120	50 150	50 150	0 0		260 420
● Contractor		0	50	50	100	100	100		400
	Total	50	330	650	600	600	350		2580

SULFUR OXIDE CONTROL R&D AND RELATED PROGRAMS

Program II STACK METEOROLOGY	**Program Element** FATE OF SO_X	**Identification/Contract No.** NCAPC-II-B

Initiation date FY 1968	**Est. completion date** FY 1969	**1st decision review**	**2nd decision review**	**Initial contract amount**	**Estimated total costs** $79,000

Bureau responsible National Center for Air Pollution Control	**Sub organization** Meteorology	**Project director** L. E. Niemeyer

Contractor or in-house organization performing work Geophysical Corp. of America	**Location of work**

Technical description

This study of the reactions of sulfur in stack plumes involves defining power plant effluents; defining chemical behavior of effluents; designing and constructing pilot furnace to study fuels, combustion, and ambient conditions under simulated laboratory conditions; studying SO_x oxidation in a stirred reactor; studying various physical diffusion and chemical reactions under simulated conditions in a reactor.

Utility/applicability

Will be useful in determining the concentration of sulfur oxides at various distances downstream from a stack.

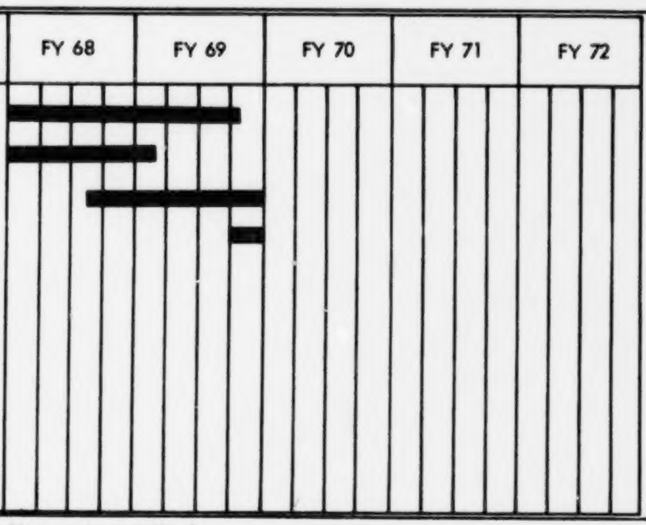
Constraints to successful/on time completion

None.

Other related or parallel R&D efforts

Plume rise and dispersion from tall stacks is complementary. Both elements are required for an effective stack meteorology model.

Tasks	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 est. completion date	Post FY 72 cost
1. Define effluents and their chemical behavior.							
2. Design and construct pilot furnace.							
3. Conduct reactor studies.							
4. Publish report.							



Funding--Obligated & estimated obligations required for future (thousands of dollars)

Fund source(s)	Total prior years	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 cost	Total cost
● Agency NCAPC		58	21					79
● Industry Edison Electric Institute Bituminous Coal Research Inst. American Petroleum Institute	(Non-Add)	(58)	(63)					(121)
Total		58	21					. 79
Program element performed by:								
● Agency								
● Contractor Geophysical Corp. of America		58	21					79
● Other (GCA also receives non-add funds)								
Total		58	21					79

FUEL DESULFURIZATION

PROGRAM III

D. Program III: Fuel Desulfurization

Fuel desulfurization is an important aspect in bringing sulfur pollution under control. For many types of sulfur pollution sources, the use of a low sulfur fuel would be found to be the preferable and sometimes the only practical solution to the pollution problem. Consequently, numerous worthy projects, which as yet cannot be well defined, are expected to be proposed for investigation in the field of desulfurization of coal, oil, and other fuels. These proposals are expected from both the private and Government sectors. Some will be predominantly oriented to the resource base with important secondary benefits to sulfur pollution control. Cooperative funding could be expected. Others may prove to be of direct benefit to pollution control and be funded solely by NCAPC. Nevertheless, experience dictates that projects will be proposed at any task level, depending on prior development, and will require research and development studies of direct or secondary benefit for pollution control. Plans for these new fuel desulfurization processes are shown on program element sheet NCAPC-III-F.

Specifically, the program on fuel desulfurization can be divided into two major parts, desulfurization of oil and desulfurization of coal.

1. Desulfurization of Oil

Processes for desulfurizing residual fuel oil have been developed to the stage of commercial applicability by various petroleum refining companies. Details of these processes are, however, usually closely held as proprietary information. In general, there is a need for cost reduction; as, for instance, by the development of improved catalysts for hydrodesulfurization. The NCAPC proposes to support limited feasibility in residual oil desulfurization to promote lower cost processes and to aid NCAPC in staying aware of industrial activities in this area. The Bureau of Mines plans numerous projects in the field of sulfur reduction in various petroleum fractions. These can be seen on program element and supplemental data sheets NCAPC-III-A, B, and C.

2. Desulfurization of Coal

The removal of pyrite from coal has a limited potential, since a portion of the sulfur is present in organic compounds in the coal itself. Furthermore, the size and distribution of the pyrite in some coals also negates its removal by conventional coal cleaning methods. To date, coal cleaning processes have been designed to remove mineral matter from coal with a minimum of coal rejects. These processes generally do not reduce the sulfur content of the coal enough to satisfy the requirements for sulfur pollution control. In some cases where requirements could be met, the rejects would be excessive and the cost excessive. Consequently, the NCAPC sought new economical processes which could clean the coal to sulfur levels adequate for pollution control. The first of these is the Pyrite-Coal Process shown on program element sheet NCAPC-III-D.

The Pyrite-Coal Process first needed more information on which coals in the United States were amenable to "deep cleaning" of pyritic sulfur. In 1965, NCAPC suggested and financed a study of the washability of utility coals to be conducted by the Bureau of Mines. This project is well under way, and work under contracts with the Illinois Geological Survey and Commercial Testing Company will generate additional data. Concurrent with work to define "deep cleanability" of coals, studies of process costs and markets for byproducts are being conducted by two teams. Arthur D. Little is working with Dorr-Oliver to investigate fluid-bed roasting of "deep cleaning" rejects; Bechtel Corporation is evaluating different processes that might be used to convert rejects having a wide range of ratios of coal to pyrite. Because of a common interest in the concept, Bituminous Coal Research is working with the NCAPC to evaluate devices for separating the pyrite from coal. Preliminary data are encouraging, and a contractor will be selected soon to design the coal-cleaning part of the process. Thus, a specific process to make available large quantities of low sulfur coal which will have direct benefits to controlling sulfur pollution is expected to be completed in 1972.

The Bureau of Mines is funding projects which are basic to new coal cleaning systems for producing a low pyrite coal. The work is needed in general to protect and expand the resource base for coal and will eventually contribute to systems which will make available large quantities of pyrite-free coal. The Bureau plans in this area are shown on program element sheet NCAPC-III-E.

Other processes of interest to NCAPC for producing low-sulfur fuels are considered and shown later under Program IV, entitled Fuel Conversion. These conversion processes usually resort to more than physical methods of separating the sulfur; they usually are independent of the type and mode of sulfur, and generally result in a "clean" fuel with different physical characteristics than those of the starting raw fuel.

Returning again to the program on Fuel Desulfurization, Figure 7 shows funding by agency. The NCAPC is planning a total expenditure of \$23,014,000 for programs which are oriented directly to SO_x control. All these funds except a small amount for contract monitoring go for contracts or are transferred to other Government agencies. Of this amount, \$17.7 million is in the area of new desulfurization processes where further development is needed but is not yet precisely defined or contracted to designated funds at the project level. These funds will be utilized for worthy research and development projects to upgrade the technology of desulfurization of coal and oil or to exploit technological breakthroughs that occur in ongoing desulfurization research. Emphasis will be placed on work involving coal. Funds will be used in cooperative efforts among Government agencies and with commercial enterprises now engaged in proprietary developments, with the aim of exploiting the desulfurization developments for maximum application to SO_x control. Since these funds are expected to go for contracts with the private sector or be transferred to other Government agencies in a coordinated program, the distribution of funds at the project level can be specified only in later editions after proposals have been received and evaluated from all sectors.

The Bureau of Mines plans to fund projects totaling \$9,722,000. These projects are in the fields of oil and coal desulfurization and are oriented to protect and broaden the resource base under the constraints of sulfur pollution control. The Office of Coal Research is planning expenditures of an additional \$500,000, similarly oriented in the field of coal alone. This is a total of \$10,222,000 being planned by other agencies which may have collateral benefits for the sulfur oxides control program of the NCAPC.

The total Federal program involving both direct and collateral benefits in the program of Fuel Desulfurization amounts to \$33,236,000. The distribution of this amount by funding agency and fiscal year is shown in Figure 7. A similar distribution, by program elements and fiscal year, is summarized in Figure 8. The detailed funding by source and performing agency can be seen on the program element and supplemental data sheets.

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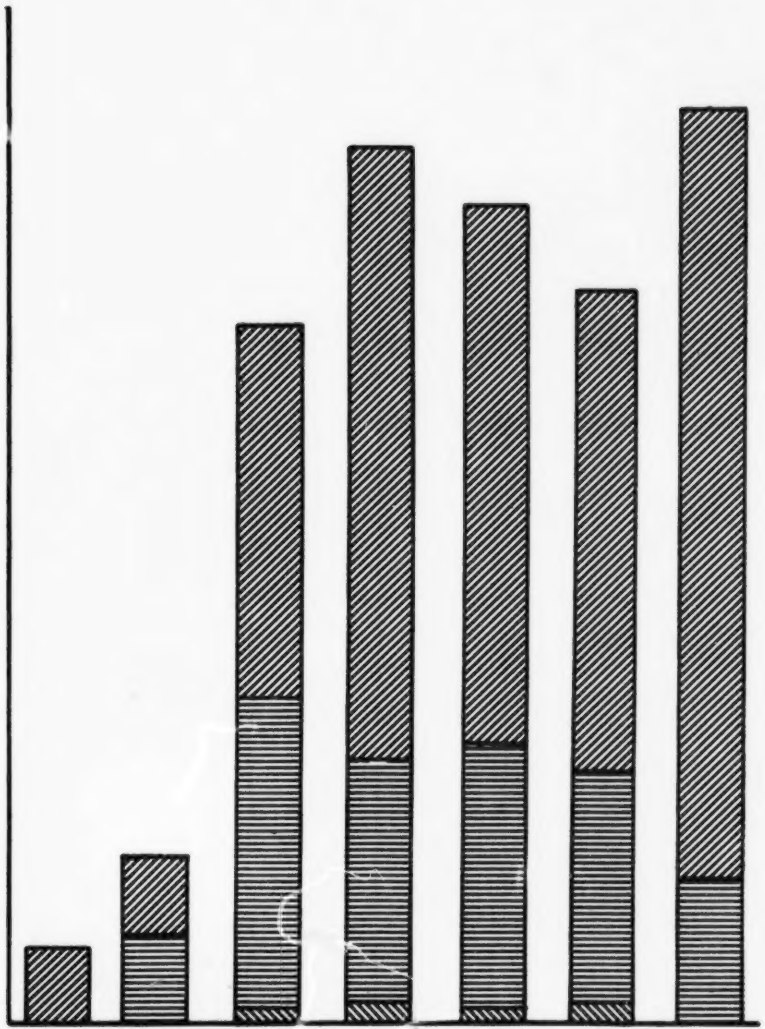
Figure 7

PROGRAM III. FUEL DESULFURIZATION

By Funding Agency
(Thousands of Dollars)

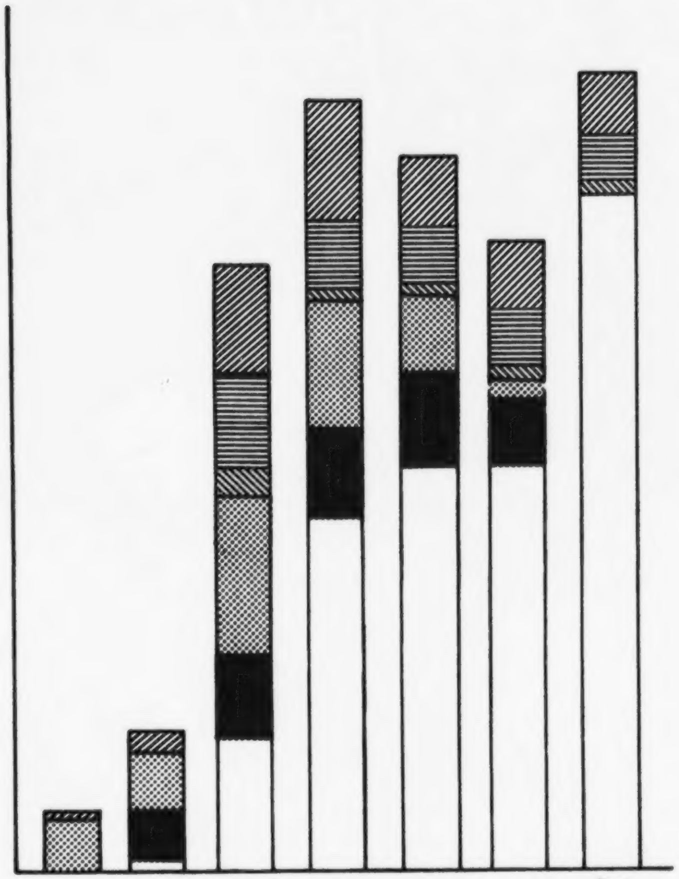


	Funding Agencies	Prior FY 68	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72	Total
▨	NCAPC	552	637	2905	4835	4305	3780	6000	23014
▤	BuMines	0	636	2406	1862	1944	1774	1100	9722
▧	OCR	0	0	100	150	100	150	0	500
▩	TVA	0	0	0	0	0	0	0	0
■	FPC	0	0	0	0	0	0	0	0
	Total	552	1273	5411	6847	6349	5704	7100	33236

Figure 8

PROGRAM III. FUEL DESULFURIZATION

By Program Element
(Thousands of Dollars)



	Program Elements	Prior FY 68	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72	Total	NCAPC Share of Total
▨	A. Desulfurization of Residual Oil	60	200	950	1050	600	600	550	4010	960
▤	B. Desulfurization of Crude Oil	0	0	850	600	500	500	450	2900	0
▧	C. Desulfurization of Petroleum Coke	0	0	250	100	100	100	100	650	0
▒	D. Pyrite-Coal Process	492	437	1405	1135	705	180	0	4354	4354
■	E. New Systems and Physical Methods of Producing Low-Pyrite Coal	0	536	756	762	844	724	0	3662	0
□	F. New Fuel Desulfurization Processes	0	100	1200	3200	3600	3600	6000	17700	17700
	Total	552	1273	5411	6847	6349	5704	7100	33236	23014

SULFUR OXIDE CONTROL R&D AND RELATED PROGRAMS

Program III FUEL DESULFURIZATION	Program Element DESULFURIZATION OF RESIDUAL OIL	Identification/Contract No. NCAPC-III-A

Initiation date 1966	Est. completion date 1975	1st decision review	2nd decision review	Initial contract amount $60,000	Estimated total costs $4,010,000

Bureau responsible National Center for Air Pollution Control	Sub organization CONTECH	Project director K. Janes
Contractor or in-house organization performing work Bureau of Mines and Others	Location of work Various	

Technical description

The petroleum industry is active in the area of desulfurization, and government in-house work cannot timely or efficiently be brought to industry's existing capabilities. Therefore, two objectives exist for funding in this area: (1) to supplement specific industry activities in a manner which will aid the industry in achieving timely desulfurization of petroleum fractions, (2) to build and maintain an in-house knowledge and awareness in the field to guide control recommendations and procedures. NCAPC projects in the area of desulfurization of petroleum fractions will be guided by a Technical Advisory Committee. NCAPC funds for this area will be drawn from Program Element "New Fuel Desulfurization Processes" when projects are indicated as being worthy of funding. The resource portion of R&D which has combined resource and air pollution control ramifications is expected to be funded by government agencies other than NCAPC.

Utility/applicability

Timely achievement of availability of desulfurized petroleum fractions and the maintenance of in-house awareness to guide control recommendations.

Constraints to successful/on time completion

Other related or parallel R&D efforts

Desulfurization of Crude Oil and Desulfurization of Petroleum Coke.

Tasks	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 est. completion date	Post FY 72 cost
1. Exploratory and supporting studies	■	■	■	■	■	FY 75	
2. Bench scale	■	■	■	■	■		
3. Pilot Plant		■	■	■	■	FY 75	

Funding--Obligated & estimated obligations required for future (thousands of dollars)

Fund source(s)	Total prior years	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 cost	Total cost
● Agency NCAPC	60	100	300	500	0	0	0	960
● Agency Bureau of Mines	0	100	650	550	600	600	550	3050
Total	60	200	950	1050	600	600	550	4010
Program element performed by:								
● Agency Bureau of Mines	0	100	650	550	600	600	550	3050
● Agency								
● Contractor Various	60	100	300	500	0	0	0	960
Total	60	200	950	1050	600	600	550	4010

SULFUR OXIDE CONTROL R&D AND RELATED PROGRAMS

Program III FUEL DESULFURIZATION	**Program Element** DESULFURIZATION OF RESIDUAL OIL	**Identification/Contract No.** NCAPC-III-A

Supplementary data and comments

Project	Task Status	Executing Contractor or Agency	Funding Source and Amount	Date		Remarks
				Start	Complete	
Economics of Desulfurizing Residual Fuel Oil	1	Bechtel Corp	NCAPC $60,000		1966	Establish recent range of costs for desulfurizing fuel oil
Sulfur Compounds in Petroleum Products	1	Bureau of Mines	Bureau of Mines $1,100,000	1968	1973	Characterization of sulfur compounds in oil to suggest desulfurization methods
Catalytic Hydrodesulfurization	2	Bureau of Mines	Bureau of Mines $200,000	1968	1969	Determine optimum operating conditions for catalytic hydrodesulfurization of No. 6 resid.
Improved Catalyst for Hydrodesulfurization of Residual	2	Hydrocarbon Research	NCAPC $900,000	1968	1971	Seek improved catalyst for selective hydrogenation of sulfur compounds in resid.
Hydrodesulfurization and Treatment	3	Bureau of Mines	Bureau of Mines $1,750,000	1969	1973	Deep desulfurization of petroleum fractions by new chemical and physical pretreatment

SULFUR OXIDE CONTROL R&D AND RELATED PROGRAMS

Program III FUEL DESULFURIZATION	**Program Element** DESULFURIZATION OF CRUDE OIL	**Identification/Contract No.** NCAPC-III-B

Initiation date	**Est. completion date**	**1st decision review**	**2nd decision review**	**Initial contract amount**	**Estimated total costs**
1969	1973				$2,900,000

Bureau responsible National Center for Air Pollution Control	**Sub organization** CONTECH	**Project director** K. Jones
Contractor or in-house organization performing work Bureau of Mines and Others	**Location of work** Various	

Technical description

The petroleum industry is active in the area of desulfurization, and government in-house work cannot timely or efficiently be brought to industry's existing capabilities. Therefore, two objectives exist for funding in this area: (1) to supplement specific industry activities in a manner which will aid the industry in achieving timely desulfurization of petroleum fractions, (2) to build and maintain an in-house knowledge and awareness in the field to guide control recommendations and procedures. NCAPC projects in the area of desulfurization of petroleum fractions will be guided by a Technical Advisory Committee. NCAPC funds for this area will be drawn from Program Element "New Fuel Desulfurization Processes" when projects are indicated as being worthy of funding. The resource portion of R&D which has combined resource and air pollution control ramifications is expected to be funded by government agencies other than NCAPC.

Utility/applicability

Timely achievement of availability of desulfurized petroleum fractions and the maintenance of in-house awareness to guide control recommendations.

Constraints to successful/on time completion

Other related or parallel R&D efforts

Desulfurization of Residual Oil and Desulfurization of Petroleum Coke

Tasks	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 est. completion date	Post FY 72 cost
1. Exploratory and supporting studies		■	■	■	■	FY 73	
2. Bench scale		■	■	■	■	FY 73	

Funding--Obligated & estimated obligations required for future (thousands of dollars)

Fund source(s)	Total prior years	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 cost	Total cost
● Agency Bureau of Mines			850	600	500	500	450	2900
● Agency								
Total			850	600	500	500	450	2900
Program element performed by:								
● Agency Bureau of Mines			850	600	500	500	450	2900
● Agency								
● Contractor								
Total			850	600	500	500	450	2900

SULFUR OXIDE CONTROL R&D AND RELATED PROGRAMS

Program III FUEL DESULFURIZATION	**Program Element** DESULFURIZATION OF CRUDE OIL	**Identification/Contract No.** NCAPC-III-B

Supplementary data and comments

Project	Task Status	Executing Contractor or Agency	Funding Agency and Amount	Date		Remarks
				Start	Complete	
Sulfur in Petroleum	1	Bureau of Mines	Bureau of Mines $500,000	1969	1973	Characterization of sulfur compounds in crude to suggest desulfurization methods
Applicability of Solvent Refining, Clay Treatment, Hydrodesulfurization to Desulfurizing Crude	1	Bureau of Mines	Bureau of Mines $150,000	1969	1969	Deep desulfurization of crude by chemical and physical pretreatment
Pretreatment for Sulfur Removal	2	Bureau of Mines	Bureau of Mines $2,250,000	1969	1973	Deep desulfurization of crude by new pretreatment method

SULFUR OXIDE CONTROL R&D AND RELATED PROGRAMS

Program III FUEL DESULFURIZATION	Program Element DESULFURIZATION OF PETROLEUM COKE	Identification/Contract No. NCAPC-III-C

Initiation date 1969	Est. completion date 1973	1st decision review	2nd decision review	Initial contract amount	Estimated total costs $650,000

Bureau responsible National Center for Air Pollution Control	Sub organization	Project director
Contractor or in-house organization performing work Bureau of Mines and Others	Location of work Various	

Technical description

The petroleum industry is active in the area of desulfurization, and government in-house work cannot timely or efficiently be brought to industry's existing capabilities. Therefore, two objectives exist for funding in this area: (1) to supplement specific industry activities in a manner which will aid the industry in achieving timely desulfurization of petroleum fractions, (2) to build and maintain an in-house knowledge and awareness in the field to guide control recommendations and procedures. NCAPC projects in the area of desulfurization of petroleum fractions will be guided by a Technical Advisory Committee. NCAPC funds for this area will be drawn from Program Element "New Fuel Desulfurization Processes" when projects are indicated as being worthy of funding. The resource portion of R&D which has combined resource and air pollution control ramifications is expected to be funded by government agencies other than NCAPC.

Utility/applicability

Timely achievement of availability of desulfurized petroleum fractions and the maintenance of in-house awareness to guide control recommendations.

Constraints to successful/on time completion

Other related or parallel R&D efforts

Desulfurization of Residual Oil and Desulfurization of Crude Oil.

Tasks	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 est. completion date	Post FY 72 cost
Exploratory and supporting studies		━━	━━	━━	━━	FY 73	

Funding--Obligated & estimated obligations required for future (thousands of dollars)

Fund source(s)	Total prior years	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 cost	Total cost
● Agency Bureau of Mines			250	100	100	100	100	650
● Agency								
Total			250	100	100	100	100	650
Program element performed by:								
● Agency Bureau of Mines			250	100	100	100	100	650
● Agency								
● Other								
Total			250	100	100	100	100	650

Program III	Program Element	Identification/Contract No.
FUEL DESULFURIZATION	DESULFURIZATION OF PETROLEUM COKE	NCAPC-III-C

Supplementary data and comments

Project	Task Status	Executing Contractor or Agency	Funding Source and Amount	Date		Remarks
				Start	Complete	
Sulfur in Petroleum Coke	1	Bureau of Mines	Bureau of Mines $500,000	1969	1973	Determine types of sulfur compounds in petroleum coke to aid in establishing methods of removal.
Applicability of Various Methods of Desulfurizing Petroleum Coke	1	Bureau of Mines	Bureau of Mines $150,000	1969	1969	

SULFUR OXIDE CONTROL R&D AND RELATED PROGRAMS

Program III FUEL DESULFURIZATION	**Program Element** DESULFURIZATION OF COAL BY PYRITE-COAL PROCESS	**Identification/Contract No.** NCAPC-III-D

Initiation date November 1964	**Est. completion date** June 1972	**1st decision review**	**2nd decision review**	**Initial contract amount**	**Estimated total costs** $4,354,000

Bureau responsible National Center for Air Pollution Control	**Sub organization** CONTECH	**Project director** T. K. Janes
Contractor or in-house organization performing work Various	**Location of work** Various	

Technical description

The process is a specific development of a system to produce essentially pyrite free coal and marketable by-products. Removal of pyritic sulfur from coal by size reduction and conventional coal cleaning methods based on differences in specific gravity between coal and inorganic constituents has been demonstrated effective for certain coals. Operation of the process to maximize pyrite removal usually results in the rejection of excessive amounts of coal with pyrite, thereby increasing process costs. A process which would utilize the pyrite-coal rejects to produce useful products could offset the cost of using coal cleaning methods to reduce sulfur dioxide pollution. The specific system will be tailored for large coal reserves near large power producing regions.

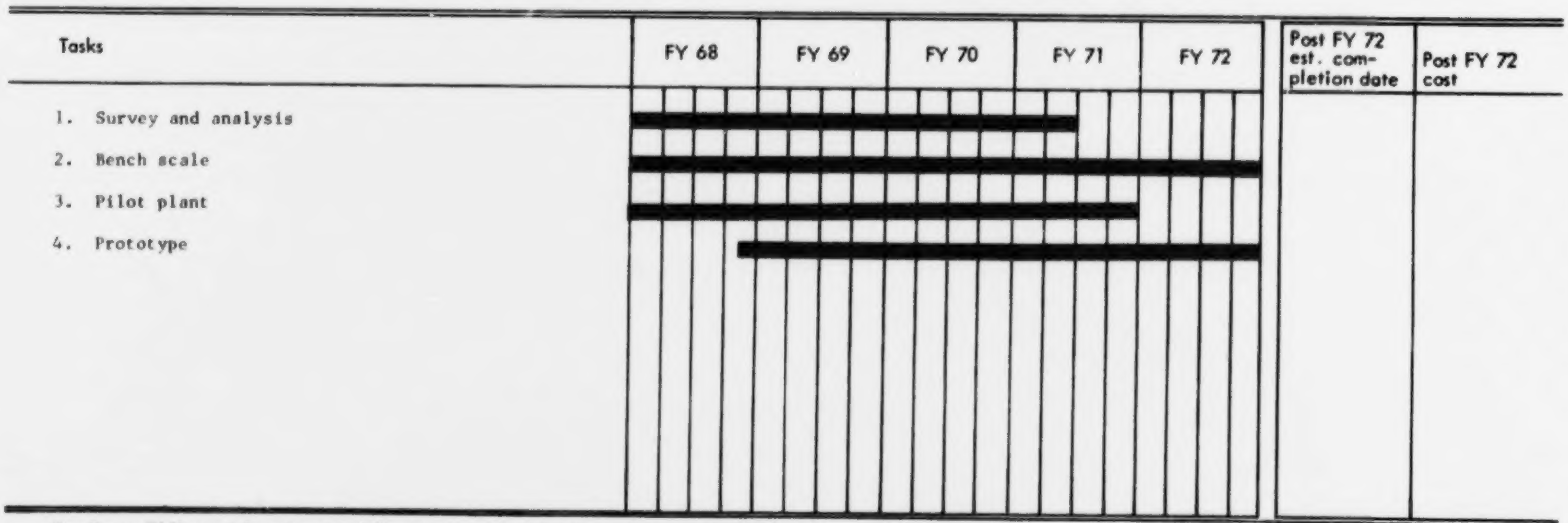
Utility/applicability

The process will produce an essentially pyrite free coal at no increase in cost (or minor increase) because of the offsetting value of the by-products produced from the coal pyrites; thus, a low sulfur coal would be available for steam generation. Successful development and use of this process will alleviate problems in solid waste disposal (gob piles), water pollution (acid run-off from gob piles), and air pollution (spontaneous combustion of gob piles), since the material going to these piles will be eliminated.

Constraints to successful/on time completion

Other related or parallel R&D efforts

Development of new pyrite free coal processes proposed under program element "New Systems and Physical Methods of Producing Pyrite-free Coal"



Funding--Obligated & estimated obligations required for future (thousands of dollars)

Fund source(s)	Total prior years	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 cost	Total cost
● Agency NCAPC	492	437	1405	1135	705	180		4354
● Agency								
Total	492	437	1405	1135	705	180		4354
Program element performed by:								
● Agency Bureau of Mines	145	130	130	130	130	130		795
● Agency								
● Contractor Various	347	307	1275	1005	575	50		3559
Total	492	437	1405	1135	705	180		4354

SULFUR OXIDE CONTROL R&D AND RELATED PROGRAMS

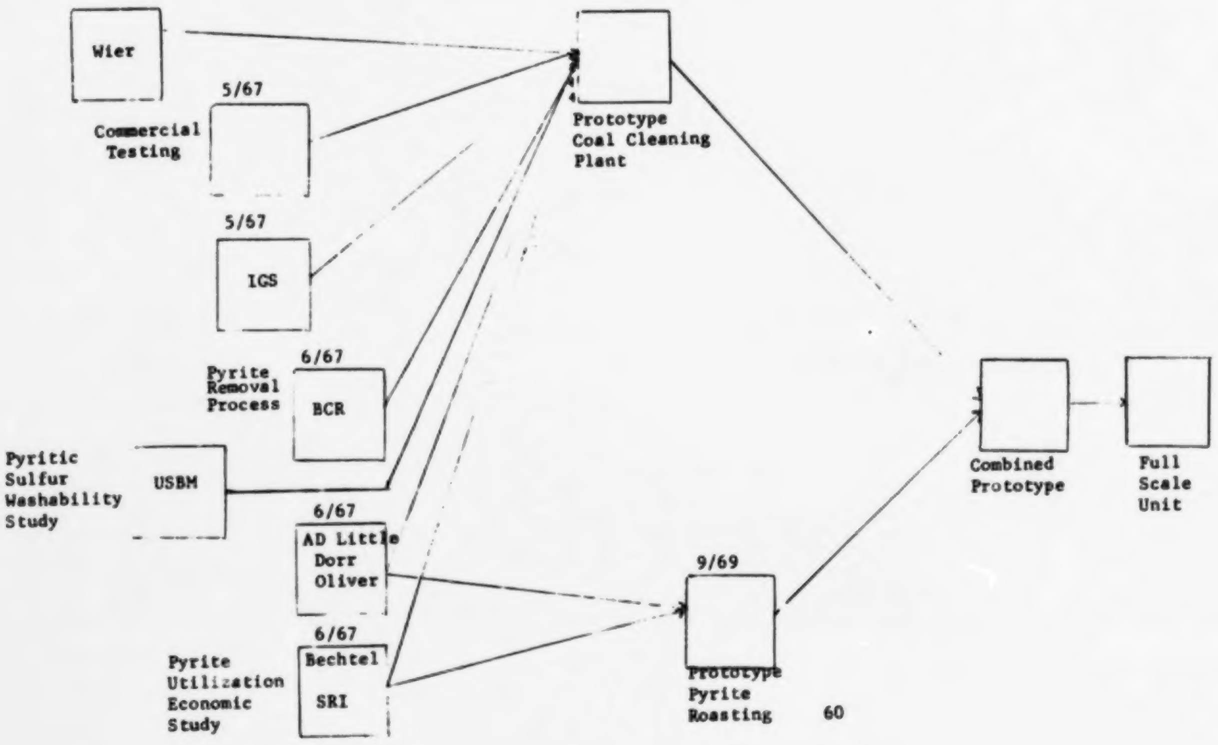
Program III	Program Element	Identification/Contract No.
FUEL DESULFURIZATION	DESULFURIZATION OF COAL BY PYRITE-COAL PROCESS	NCAPC-III-D

Supplementary data and comments

Project	Task Status	Executing Contractor or Agency	Funding Agency and Amount	Date Start	Date Complete	Remarks
Feasibility of Coal Desulfurization and of Iron & Sulfur Recovery from Pyrite	1	Paul Weir Co.	NCAPC $27,000	1965	1966	Determined feasibility of Pyrite-Coal Process and tightened problem definition and process conceptualization
Economic Study of Fluid Bed Roasting of Pyrite-Coal	1	A.D. Little and Dorr-Oliver	NCAPC $67,000	1967	1968	Studied conventional processes for roasting pyrite containing coal and product marketability and values
Pyrite Utilization and Economic Study	1	Bechtel & SRI	NCAPC $93,000	1967	1968	Study ore processes for making marketable products of pyrite containing coal and their potential values
Pyrite Sulfur Washability Study	2	Bureau of Mines	NCAPC $795,000	1965	1967	Determine pyritic sulfur washability of major suppliers to steam generating units and identify coal areas amenable to production of 1% S coal by pyrite-coal process
Pyrite Sulfur Washability Study	2	Commercial Testing & Engineering Co	NCAPC $144,000	1967	1968	Determine specific sources of coal with demonstrated potential for producing low pyritic coal
Illinois Coal Evaluation	2	Ill. Geological Survey	NCAPC $175,000	1967	1969	50-50 cooperative study of Ill. coals amenable to pyrite removal

Comments:

1. Pilot plant studies funded by NCAPC and performed by Bituminous Coal Research will evaluate commercial methods, process equipment, and sequence of arrangement of equipment to process the promising coal fields surveyed to pyritic free coal in the <30 and < 200 mesh sizes. The work will establish the front end of the pyrite-coal process and dove-tail with results of pyrite-coal utilization and economic studies of A. D. Little and Bechtel to establish the overall process to undertake on a prototype scale.
2. The relationships of the Desulfurization of Coal by Pyrite Coal Process Program Element tasks and projects are shown graphically below.


Wier
5/67
Commercial Testing
5/67
IGS
6/67
Pyrite Removal Process
BCR
Pyritic Sulfur Washability Study
USBM
6/67
AD Little Dorr Oliver
6/67
Pyrite Utilization Economic Study
Bechtel SRI
Prototype Coal Cleaning Plant
9/69
Prototype Pyrite Roasting
Combined Prototype
Full Scale Unit

SULFUR OXIDE CONTROL R&D AND RELATED PROGRAMS

Program III FUEL DESULFURIZATION	**Program Element** NEW SYSTEMS AND PHYSICAL METHODS OF PRODUCING LOW PYRITE COAL				**Identification/Contract No.** NCAPC-III-E
Initiation date 1968	**Est. completion date** 1972	**1st decision review**	**2nd decision review**	**Initial contract amount**	**Estimated total costs** $3,622,000
Bureau responsible Bureau of Mines and National Center for Air Pollution Control			**Sub organization**		**Project director** K. Janes
Contractor or in-house organization performing work Various			**Location of work** Various		

Technical description

New systems will be developed which incorporate coal preparation methods and produce low pyrite coal and marketable by-products. The systems will be amenable to large coal fields and designed to produce coal essentially pyrite free. The systems will be designed to yield marketable by-products so that the overall system may achieve profitable operation under competitive pricing of the "clean" coal and the by-products.

In addition, new coal preparation methods will be developed to provide competitive "clean" coal on their own merit or to be incorporated advantageously into "clean" coal-marketable by-product systems. See Following page for specific projects.

Utility/applicability

Will provide economical processes for increasing the supply of low sulfur coal to the energy market.

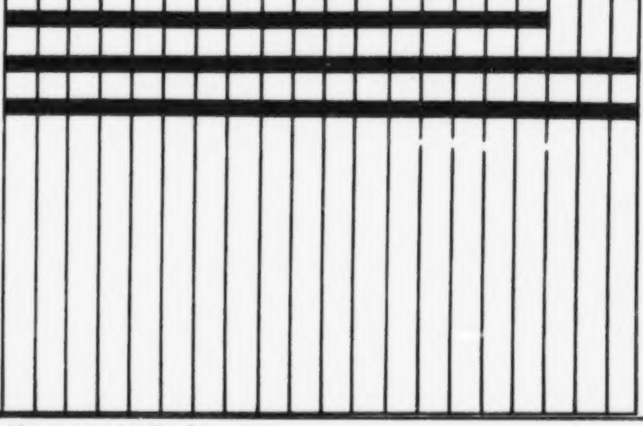
Constraints to successful/on time completion

Lack of ideas for new systems and separation methods.

Other related or parallel R&D efforts

The NCAPC Pyrite-Coal Process is one of the systems defined specifically enough to warrant a separate program element at this time.

Tasks	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 est. completion date	Post FY 72 cost
1. Feasibility and exploratory							
2. Bench scale							
3. Pilot Plant							



Funding--Obligated & estimated obligations required for future (thousands of dollars)

Fund source(s)	Total prior years	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 cost	Total cost
● Agency Bureau of Mines		536	756	762	844	724		3622
● Agency								
Total		536	756	762	844	724		3622
Program element performed by:								
● Agency Bureau of Mines		536	756	762	844	724		3622
● Agency								
● Other								
Total		536	756	762	844	724		3622

SULFUR OXIDE CONTROL R&D AND RELATED PROGRAMS

Program III FUEL DESULFURIZATION	**Program Element** NEW SYSTEMS AND PHYSICAL METHODS OF PRODUCING LOW PYRITE COAL	**Identification/Contract No.** NCAPC-III-E

Supplementary data and comments The presently designated projects and their task status which make up this program element are listed below:

Project	Task Status	Executing Contractor or Agency	Funding Source and Amount	Date		Remarks
				Start	Complete	
Determination of Sulfur Modes in Coal	1	Bureau of Mines	Bureau of Mines $148,000	1968	1972	Relates S-33 isotope to forms of S in various ranks of coal
Reduction of Sulfur in Steam Coal	1	Office of Coal Research	OCR Awaiting funds (500,000)	--	48 mo.	Tests on grinding various coals and separating S and pyrite
Effect of Crushing on Magnetic Properties of Coal	1	Bureau of Mines	Bureau of Mines $81,000	1968	1972	Compare magnetic properties of crushed pyrite and pyrite in crushed coal
Magnetic Separation of Pyrite Using High Frequency Waves	2	Bureau of Mines	Bureau of Mines $945,000	1968	1972	Optimum frequency for conversion of pyrite to pyrrhotite
Removal of Pyrite & Ash from Coal by Dry Methods	2	Bureau of Mines	Bureau of Mines $189,000	1968	1970	Remove pyrite from coal by air entrainment
Separation of Pyrite from Coal by Electrostatic Methods	2	Bureau of Mines	Bureau of Mines $170,000	1968	1970	Remove pyrite from coal by high intensity electrostatic field
Electrokinetic Separation of Pyrite from Coal	2	Bureau of Mines	Bureau of Mines $335,000	1968	1972	Remove pyrite from coal by electrokinetic techniques in water
Removal of Pyrite from Coal by Tabling	3	Bureau of Mines	Bureau of Mines $146,000	1968	1972	Effect of feed size on washing efficiency for sulfur
Desulfurization of Coal by Froth Flotation	3	Bureau of Mines	Bureau of Mines $589,000	1968	1972	Reagents sought to depress pyrite in coal slurry
Washing Fine Sizes of Coal Using Unconventional Methods	3	Bureau of Mines	Bureau of Mines $230,000	1968	1972	Remove pyrite by dense medium cyclone and recover magnetite
Separation of Pyrite from Coal Using Centrifugal Methods	3	Bureau of Mines	Bureau of Mines $289,000	1968	1972	Separate pyrite from coal using cyclones and solid bowl centrifuges

Comments:

The above projects are basic research and equipment performance oriented without specific end objectives of achieving economical systems yielding essentially pyritic-free coal. The work described in the projects is needed in general and will eventually contribute to systems which will make available large quantities of pyritic-free coal.

SULFUR OXIDE CONTROL R&D AND RELATED PROGRAMS

Program III FUEL DESULFURIZATION	**Program Element** NEW FUEL DESULFURIZATION PROCESSES	**Identification/Contract No.** NCAPC-III-F

Initiation date July 1967	**Est. completion date** June 1975	**1st decision review**	**2nd decision review**	**Initial contract amount**	**Estimated total costs** $17,700,000

Bureau responsible National Center for Air Pollution Control	**Sub organization** CONTECH	**Project director** Varied

Contractor or in-house organization performing work Varied	**Location of work** Varied

Technical description

Worthy projects, which are not yet well defined, in the field of desulfurization of coal, oil, and other fuels will be studied on a scale necessary to achieve technical objectives. Experience dictates that funds be provided for worthy unsolicited proposals and for new proposals from both the government and private sector. Projects may start at any task level depending on prior development and may be for studies of direct or secondary benefit for air pollution control. NCAPC funds may be expected to support all or a major portion of the proposals which have merit and have a direct benefit to SO_x pollution control. Projects which have resources R&D (ie., more effective uses of coal, oil, gas, etc.) as the primary objective and secondary benefits which may accrue to air pollution control will be funded cooperatively. NCAPC funding can be expected to cover the cost of the project which accrues to the benefit of air pollution control.

Utility/applicability

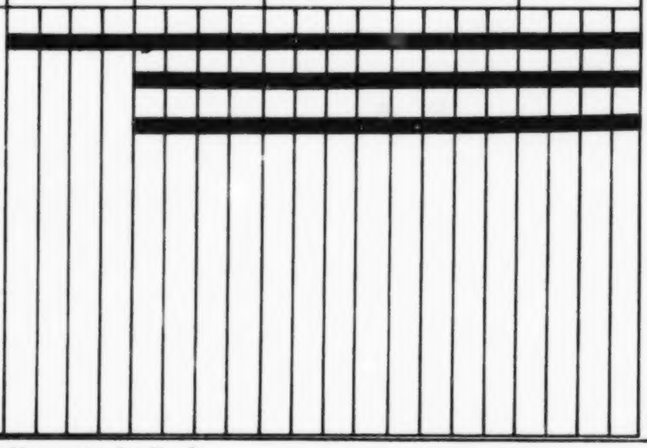
Will provide new processes to increase the availability of low sulfur fuels.

Constraints to successful/on time completion

Funds are known to be required to support the general steps which are listed below as tasks and which are required for process development; however, exact funds cannot be prescribed until the detailed project proposals are submitted in the future and are evaluated. Actual fund requirements may be higher or lower after specific proposals have been favorably evaluated and selected.

Other related or parallel R&D efforts

All those specifically designed in the Fuel Desulfurization Program.



Tasks	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 est. completion date	Post FY 72 cost
1. Exploratory and supporting studies						FY 75	
2. Bench scale							
3. Pilot plant							

Funding--Obligated & estimated obligations required for future (thousands of dollars)

Fund source(s)	Total prior years	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 cost	Total cost
● Agency NCAPC		100	1200	3200	3600	3600	6000	17,700
● Agency								
Total								
Program element performed by:								
● Agency								
● Contractor								
● Other Various								
Total		100	1200	3200	3600	3600	6000	17,700

FUEL CONVERSION

PROGRAM IV

E. Program IV: Fuel Conversion

The conversion of coal to gaseous, liquid, or modified solid fuels has been, and is being, pursued by the Bureau of Mines and the Office of Coal Research primarily for the purpose of improving the nation's fossil fuel outlook by making coal a more attractive source of energy. Most of the conversion processes are inherently sensitive to sulfur, and it must be removed prior to the critical stage in those sensitive processes. A collateral benefit in the ultimate control of SO_x pollution is derived from successful development of these processes. The NCAPC sees the successful development of conversion processes as an important contribution toward bringing SO_x under control. Because the primary objective of this work is oriented toward the resource base, the effort expended in coal conversion research is not considered to be a direct part of the SO_x control development program. All current support for this work comes from independent activities of the Bureau of Mines and the Office of Coal Research. Nevertheless, facets of some of the conversion processes can be advanced to the mutual benefit of both the resource and the air pollution control interests by developments from other processes which were tailored specifically for control of sulfur oxides. For example, the molten salt gasification process funded by OCR is similar in a systems sense to the molten carbonate process funded by NCAPC for for scrubbing SO_x from flue gases. Potential for interchange of technology and the advancement of both processes exists. Similar situations exist in other conversion processes. NCAPC plans cooperative funding in such processes.

Conversion processes are known also in which sulfur is not inherently harmful to the process. Yet these processes can yield a fuel low in sulfur. For example, the Low Ash Coal Process which has been funded by OCR has as its primary objective the removal of mineral matter from the coal by dissolving the coal, filtering the mineral matter, and reconstituting the coal by evaporation of the solvent. Since pyritic sulfur is in the mineral matter, the sulfur content of the coal is also greatly reduced. Although not investigated by OCR, the organic sulfur in the coal can also be reduced by the addition of hydrogen at the point where the coal is dissolved. Such a process would provide a coal low in both organic and pyritic sulfur which is not provided by conventional physical separation methods of coal preparation. The reconstituted coal has a relatively low melting point, and it also can be pulverized easily. Thus, it can be burned as a low sulfur oil or a powdered coal in existing combustion equipment of various sizes and types with a minimum of modification. It can be used in many industrial and commercial installations and in numerous existing public utility power plants, where space is not available for installation of flue gas treating equipment. Earlier cost estimates indicate the cost to be less than that of the conversion of coal to high Btu gas. NCAPC is evaluating the solvent refined coal process with particular emphasis on the novel feature of removing the organic sulfur.

In addition, NCAPC is evaluating the potential of systems for utilizing refuse as a means of modifying and producing low-sulfur fuel for power generation. Two pollution control objectives will be served by the successful development of such systems.

NCAPC plans the development of other fuel conversion processes not yet well enough defined to list at the project level. Experience has shown that many technically sound proposals, solicited and unsolicited, are received for process development. Noteworthy proposals may appear from either the Government or private sector. Because of the advanced state of the art of many fuel conversion processes, a large proportion of the funding is expected to be for large pilot plant and prototype scale work.

The total funding required for Program IV, Fuel Conversion, is $191,959,000 for all agencies. NCAPC plans to expend $53,091,000 in this area for work primarily oriented toward SO_x control. Of this amount, $1,091,000 is designated at the project level, and the balance of $52,000,000 is undesignated at the project level but, as previously stated, is largely expected to be used for projects at the large pilot plant or prototype scale.

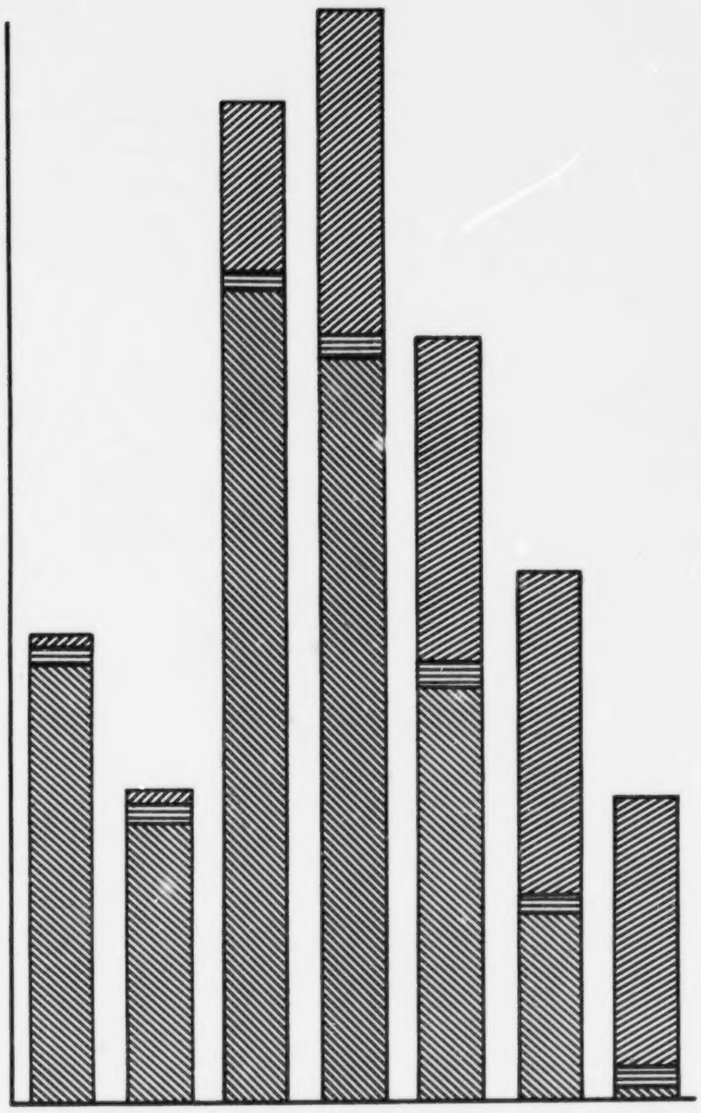
The Bureau of Mines and the Office of Coal Research plan to fund a total of $7,497,000 and $131,371,000, respectively, in fuel conversion projects with a primary objective of protecting and broadening the energy base for coal. These projects are expected to have secondary benefits of considerable impact on control of SO_x.

The distribution of the funds by funding agency and fiscal year is shown in Figure 9. A similar distribution, by program elements and fiscal year, is summarized in Figure 10. Details of the funding by source and performing organization are shown on the program element sheets that follow the figures.

Figure 9

PROGRAM IV. FUEL CONVERSION

By Funding Agency
(Thousands of Dollars)



	Funding Agencies	Prior FY 68	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72	Total
▨	NCAPC	96	150	7845	15000	15000	15000	0	53091
☰	BuMines	2042	685	890	1030	1200	800	850	7497
▧	OCR	18589	12684	37409	34323	19048	8740	578	131371
▩	TVA	0	0	0	0	0	0	0	0
■	FPC	0	0	0	0	0	0	0	0
	Total	20727	13519	46144	50353	35248	24540	1428	191959

Figure 10

PROGRAM IV. FUEL CONVERSION

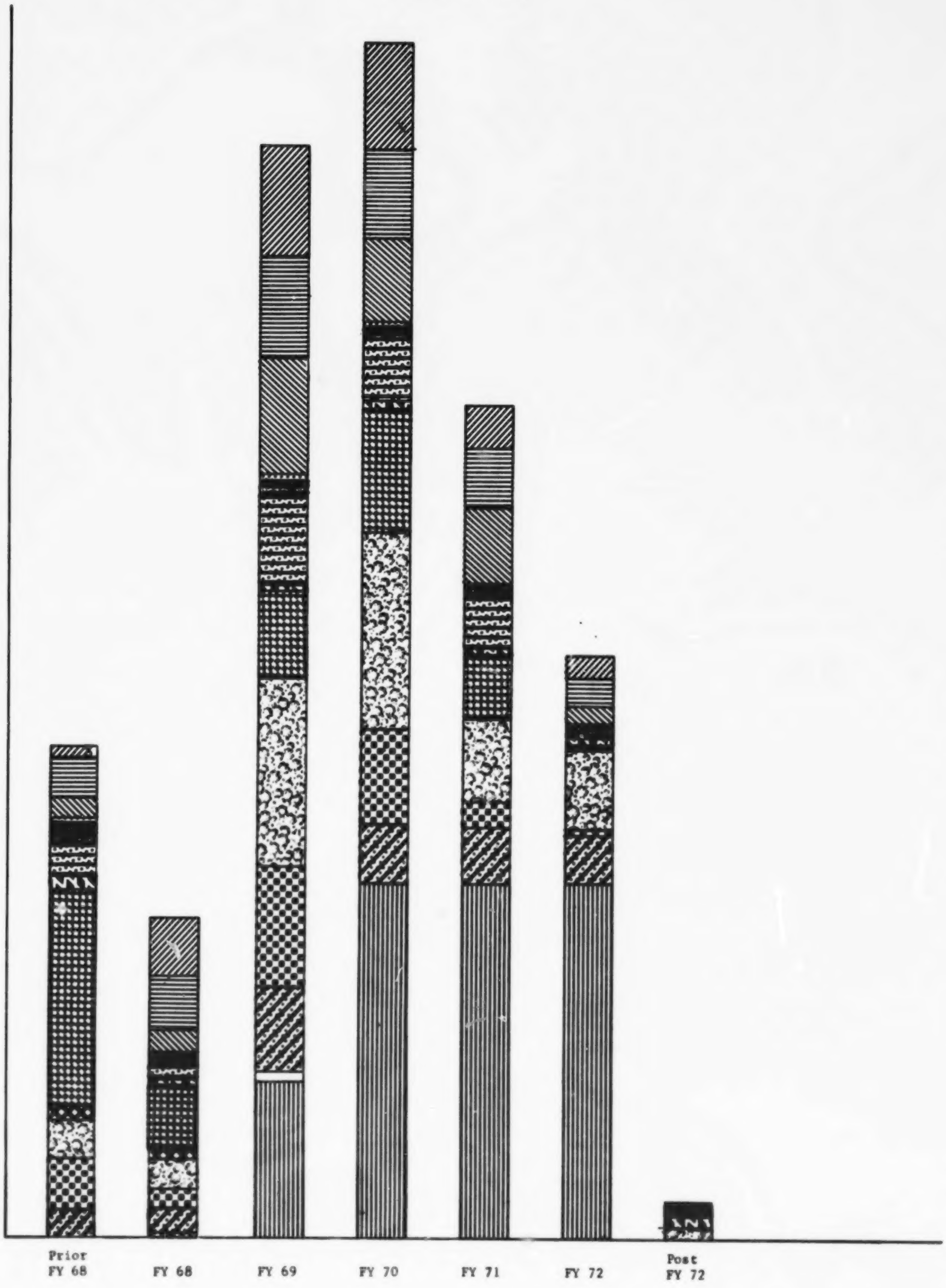
By Program Element
(Thousands of Dollars)

	Program Elements	Prior FY 68	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72	Total	NCAPC Share of Total
▨	A. Molten Salt Gasification	792	2678	4700	4650	1850	800	0	15470	500
▤	B. Hydrogasification	1678	2285	4300	3750	2500	1100	78	15691	0
▧	C. CO_2 Acceptor Process for Lignite Gasification	907	1000	5350	3500	3200	800	0	14757	0
▦	D. Gasification Optimization	15	30	70	48	0	0	0	163	0
■	E. Fixed Bed Gasification	650	280	330	330	500	350	350	2790	0
▩	F. Sulfur Control by Means of Coal Gasification	96	0	95	0	0	0	0	191	191
≋	G. Synthetic Pipeline Gas from Coal	1425	600	4000	2800	2200	400	0	11425	0
⩘	H. Catalytic Methanation	570	120	160	250	200	450	500	2250	0
▦	I. Production of Synthetic Crude Oil from Coal (GASOLINE)	9212	2625	3729	5225	2730	100	0	23621	0
▩	J. Fluidization of Resid-Coal to Yield Liquid Solid Boiler Fuel (SEACOKE)	522	378	0	0	0	0	0	900	0
▩	K. H-Coal Process	1526	1248	8000	8250	3500	3500	500	26524	0
▩	L. Char-Oil Energy Development (COED)	2134	725	4590	4050	1168	40	0	12707	0
▨	M. Low-Ash Coal	1200	1400	3570	2500	2400	2000	0	13070	0
□	N. Solvent Refined Coal	0	0	250	0	0	0	0	250	250
▥	O. Refuse as a Low Sulfur Fuel	0	150	0	0	0	0	0	150	150
▥	P. Undesignated Fuel Conversion	0	0	7000	15000	15000	15000	0	52000	52000
	Total	20727	13519	46144	50353	35248	24540	1428	191959	53091

Figure 10 (Continued)

PROGRAM IV. FUEL CONVERSION (CONTINUED)

By Program Element
(Thousands of Dollars)



SULFUR OXIDE CONTROL R&D AND RELATED PROGRAMS

Program IV FUEL CONVERSION	**Program Element** MOLTEN SALT GASIFICATION	**Identification/Contract No.** NCAPC-IV-A

Initiation date	**Est. completion date**	**1st decision review**	**2nd decision review**	**Initial contract amount**	**Estimated total costs**
June 1964	June 1972				$15,470,000

Bureau responsible	**Sub organization**	**Project director**
Office of Coal Research	Utilization Division	Cochran

Contractor or in-house organization performing work	**Location of work**
M. W. Kellogg Company	New Market, New Jersey

Technical description

Coal and steam is introduced into molten sodium carbonate at about 400 psig and 1800° F, producing a synthesis gas which is cleaned and methanated to a pipeline quality gas. The molten salt is recycled to another vessel where it is blown with air to burn the residual coal, thus furnishing the heat for the reaction. The salt is recycled through a recovery section to remove ash and sulfur. No sulfur leaves in either the synthesis gas or flue gas. This recent discovery of the mechanism of sulfur removal has resulted in a modification of the process flowsheet to eliminate the gas sulfur clean-up system and consideration of the addition of a claus process to the set salt regeneration system to recover elemental sulfur. Because of lack of funds, this project has been terminated "without prejudice."

Utility/applicability

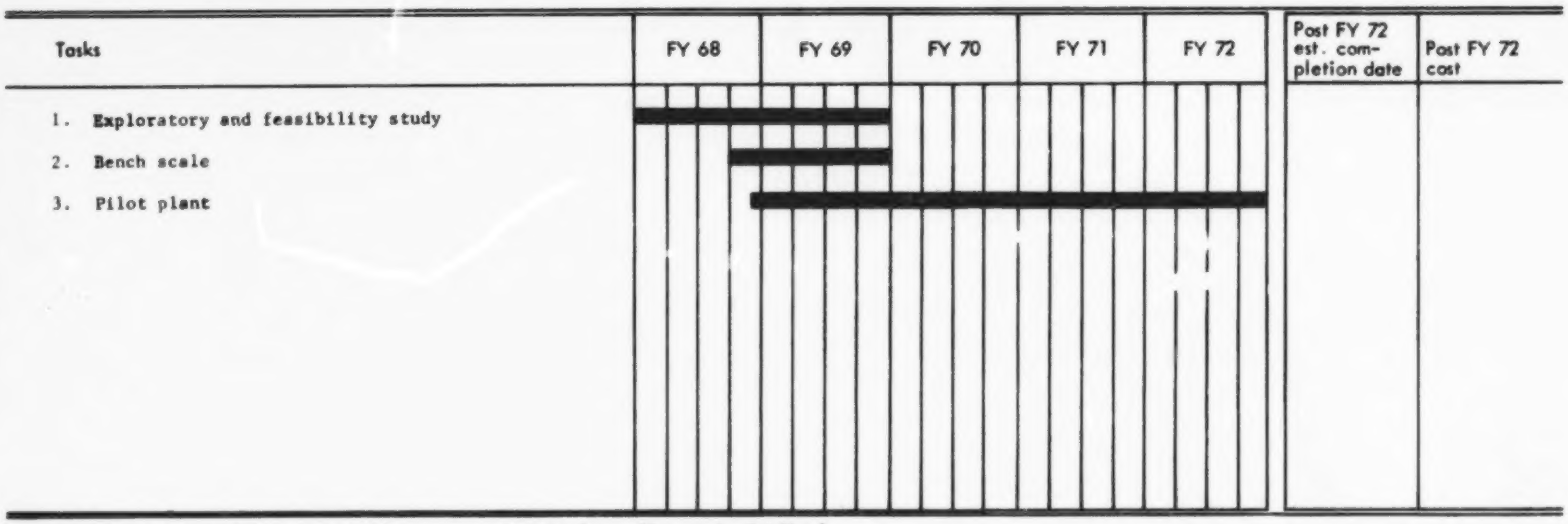
The availability of a very low sulfur gas fuel at competitive cost made from sulfur bearing coal; the elimination of all SO_x effluent to atmosphere; the recovery and sale of elemental sulfur.

Constraints to successful/on time completion

The availability of funds; the ability to develop a satisfactory molten salt containment and circulating system made of dense cast aluminum - the only material yet found which will resist corrosive action of molten sodium carbonate; the ability to develop a satisfactory large-scale salt regeneration system.

Other related or parallel R&D efforts

Hydrogasification (ITG); Lignite Gasification (Consolidation Coal); Two-Stage Gasification (BCR)



Funding--Obligated & estimated obligations required for future (thousands of dollars)

Fund source(s)	Total prior years	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 cost	Total cost
● Agency OCR	792	2,678	4,200	4,650	1,850	800		14,970
● Agency NCAPC			500					500
Total	792	2,678	4,700	4,650	1,850	800		15,470
Program element performed by:								
● Agency								
● Contractor M. W. Kellogg Company	792	2,678	4,700	4,650	1,850	800		15,470
● Other								
Total	792	2,678	4,700	4,650	1,850	800		15,470

SULFUR OXIDE CONTROL R&D AND RELATED PROGRAMS

Program IV FUEL CONVERSION	Program Element HYDROGASIFICATION	Identification/Contract No. NCAPC-IV-B

Initiation date	Est. completion date	1st decision review	2nd decision review	Initial contract amount	Estimated total costs
July 1964	August 1973				$ 15,691,000

Bureau responsible	Sub organization	Project director
Bureau of Mines and Office of Coal Research		Various

Contractor or in-house organization performing work	Location of work
Bureau of Mines and Institute of Gas Technology	Bruceton, Pa., Chicago, Ill.; and New York City.

Technical description

Coal or char is gasified to produce hydrogen rich in methane. These gases are cleaned of sulfur and methanated to produce a pipeline quality gas. (OCR-IGT) and Bureau of Mines hydrogasification processes are comprised of different steps. Comparative efficiencies are not yet firmly established. (OCR-IGT) process is currently on a larger scale, and includes development of a high output, low cost gas producer that could be used in an improved conventional power cycle.

Utility/applicability

Additional supplies of gas manufactured from high sulfur coal will be available for low sulfur fuel use. Coal can continue to supply an energy market as a transformed low sulfur methane.

Constraints to successful/on time completion

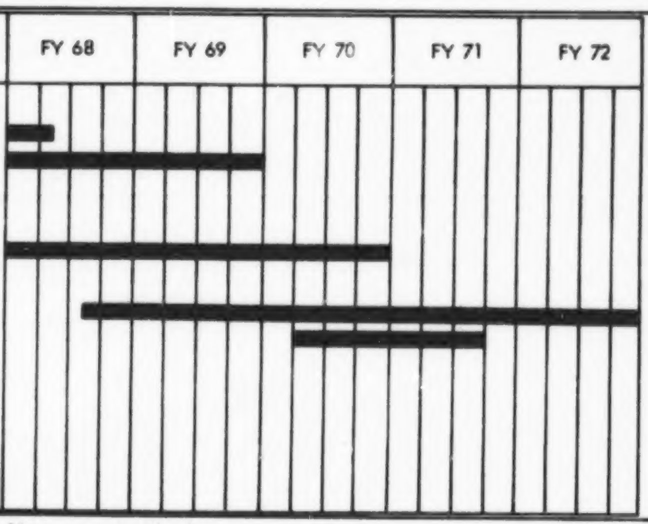
Lag in development of hydrogasification components and of the development of dependable economical hydrogen supply processes.

Other related or parallel R&D efforts

Lignite Gasification (Consolidation Coal), Pipeline Gas (BCR), Molten Salt Gasification (M. W. Kellogg).

Tasks

1. Design
   - OCR (engineering design)
   - Bureau of Mines (component design)
2. Bench scale
   - OCR (completed)
   - Bureau of Mines
3. Pilot Plant
   - OCR
   - Bureau of Mines



Post FY 72 est. completion date	Post FY 72 cost
1973	$78,000

Funding--Obligated & estimated obligations required for future (thousands of dollars)

Fund source(s)		Total prior years	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 cost	Total cost
● Agency	OCR	856	2000	3900	3300	2000	1100	78	13234
● Agency	Bureau of Mines	822	285	400	450	500	0	0	2457
	Total	1678	2285	4300	3750	2500	1100	78	15691
Program element performed by:									
● Agency	Bureau of Mines	822	285	400	450	500	0	0	2457
● Contractor	Institute of Gas Technology	856	2000	3900	3300	2000	1100	78	13234
● Other	AGA funds (non-add)	(856)	(328)	(300)	(300)	(300)	(300)	(150)	(2534)
	Total	1678	2285	4300	3750	2500	1100	78	15691

SULFUR OXIDE CONTROL R&D AND RELATED PROGRAMS

Program IV FUEL CONVERSION	**Program Element** CO_2 ACCEPTOR PROCESS FOR LIGNITE GASIFICATION	**Identification/Contract No.** NCAPC-IV-C

Initiation date	**Est. completion date**	**1st decision review**	**2nd decision review**	**Initial contract amount**	**Estimated total costs**
June 1964	June 1972			$ 8,500,000	$ 14,757,000

Bureau responsible	**Sub organization**	**Project director**
Office of Coal Research	Utilization Division	Cochran

Contractor or in-house organization performing work	**Location of work**
Consolidation Coal Company	Library, Pa., Charlotte, N.C., Rapid City, S.D.

Technical description

Lignite is contacted in a fluidized bed with calcined dolomite and steam. The calcine combines with CO_2 in an exothermic reaction and an overhead stream of CO_2 free low sulfur synthesis gas is taken off for purification and methanation to a "pipeline quality gas." The carbonated calcine, together with residual char, is recycled to a regenerator where, in an air fluidized bed, the char is burned to recalcine the "acceptor." The flue gas atmosphere is sulfur free as the sulfur combines with the acceptor fines and is removed with the ash. A variation of the process, reported in some detail but not yet extensively experimentally developed, has an indicated potential of producing a low sulfur solid boiler fuel at very low cost. Plans now are to construct and operate a pilot plant to produce pipeline quality gas. Additional work to develop the low sulfur solid fuel process is contemplated.

Utility/applicability

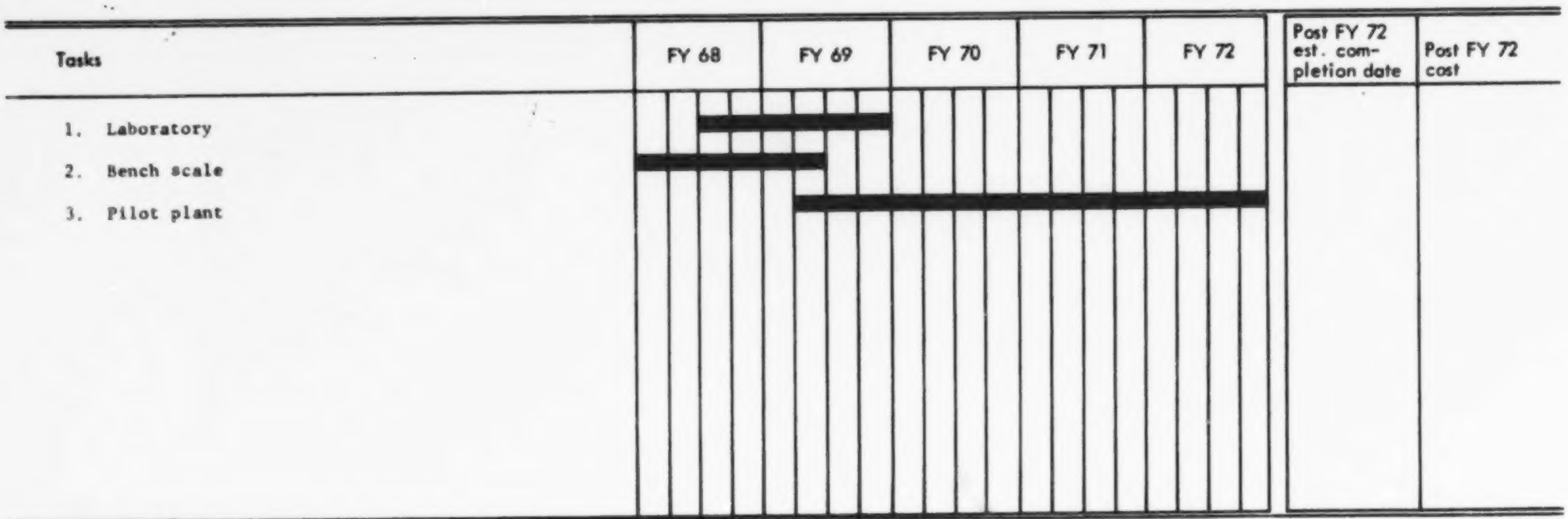
The availability of low sulfur pipeline gas made from sulfur containing coals at a competitive price. The elimination of SO_x effluent to the atmosphere. The availability of low sulfur fuel for central generating stations made from sulfur bearing coal at very low, in certain cases negligible, increment costs.

Constraints to successful/on time completion

The availability of funding.

Other related or parallel R&D efforts

Gasification (ICT) (BCR); Molten Salt Gasification (Kellogg); and Low Sulfur Char Process (FMC).



Funding--Obligated & estimated obligations required for future (thousands of dollars)

Fund source(s)	Total prior years	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 cost	Total cost
● Agency OCR	907	1000	5350	3500	3200	800		14757
● Agency								
Total	907	1000	5350	3500	3200	800		14757
Program element performed by:								
● Agency								
● Contractor Consolidation Coal Co.	907	1000	5350	3500	3200	800		14757
● Other								
Total	907	1000	5350	3500	3200	800		14757

SULFUR OXIDE CONTROL R&D AND RELATED PROGRAMS

Program IV FUEL CONVERSION		**Program Element** GASIFICATION OPTIMIZATION			**Identification/Contract No.** NCAPC-IV-D
Initiation date November 1966	**Est. completion date** November 1969	**1st decision review**	**2nd decision review**	**Initial contract amount** $163,000	**Estimated total costs** $163,000
Bureau responsible Office of Coal Research			**Sub organization** Utilization		**Project director** Cochran
Contractor or in-house organization performing work West Virginia University			**Location of work** Morgantown, West Virginia		

Technical description

The objective is to establish a generalized standard method for evaluating coal gasification processes, combinations of processes, and future changes in such processes. All available optimization techniques are to be considered with special emphasis on the dynamic optimization method, including dynamic programming, the discrete version of the generalized-maximum principle, and the continuous version of the generalized-maximum principle considered both stochastically and deterministically.

Utility/applicability

Assist in determining the optimal processes for manufacturing very low sulfur gas fuel from sulfur bearing coal.

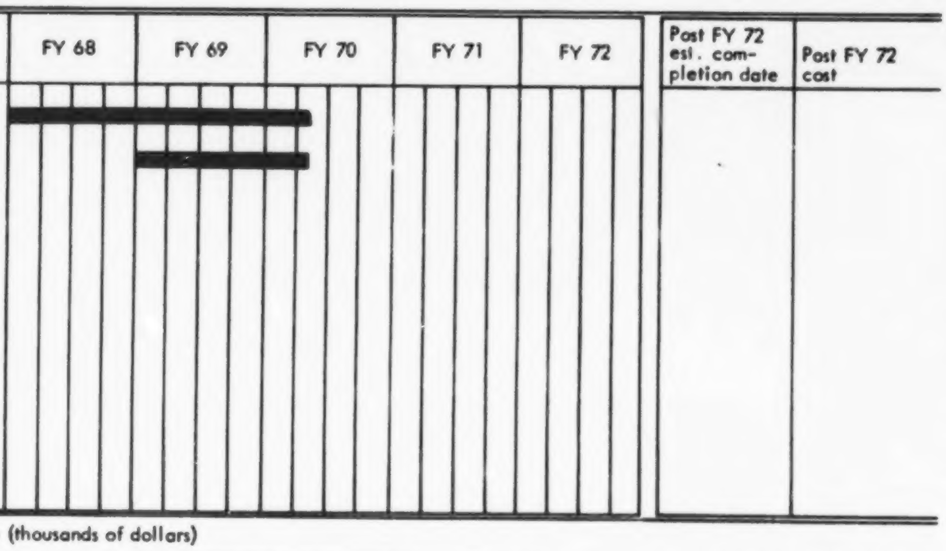
Constraints to successful/on time completion

Other related or parallel R&D efforts

Hydrogasification (IGT); Molten Salt Gasification (Kellogg); Lignite Gasification (Consolidation Coal); Two-Stage Gasification (BCR); all liquid conversion processes if this project is successful.

Tasks

1. Basic studies and reporting
2. Computer studies



Funding--Obligated & estimated obligations required for future (thousands of dollars)

Fund source(s)	Total prior years	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 cost	Total cost
● Agency OCR	15	30	70	48				163
● Agency								
Total	15	30	70	48				163
Program element performed by:								
● Agency								
● Contractor West Virginia University	15	30	70	48				163
● Other								
Total	15	30	70	48				163

SULFUR OXIDE CONTROL R&D AND RELATED PROGRAMS

Program IV FUEL CONVERSION	**Program Element** FIXED-BED GASIFICATION	**Identification/Contract No.** NCAPC-IV-E

Initiation date 1964	**Est. completion date** 1973	**1st decision review**	**2nd decision review**	**Initial contract amount**	**Estimated total costs** $2,790,000

Bureau responsible Bureau of Mines	**Sub organization**	**Project director**
Contractor or in-house organization performing work Bureau of Mines	**Location of work** Morgantown, West Virginia	

Technical description

Sized coals of various caking qualities will be gasified with air and/or steam and oxygen to produce producer gas and synthesis gas. Under pressure in a fixed-bed Lurgi-type gasifier equipped with a variable speed grade and adjustable stirrer, optimum operation with respect to throughput and pretreatment requirements will be attained. The gasifier will then be converted for slagging operation. Concurrently with operation of gasifier, methods for removing particulate matter and sulfur compounds from the hot gas will be adapted, such as electrostatic precipitation and treatment with hot iron oxide.

Utility/applicability

The gas produced would be clean, sulfur-free, industrial or high-temperature gas turbine fuel; with oxygen it would be synthesis gas.

Constraints to successful/on time completion

Other related or parallel R&D efforts

Tasks	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 est. completion date	Post FY 72 cost
1. Bench scale	━━━	━━━					
2. Pilot plant	━━━	━━━	━━━	━━━	━━━	FY 73	350,000

Funding--Obligated & estimated obligations required for future (thousands of dollars)

Fund source(s)	Total prior years	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 cost	Total cost
● Agency Bureau of Mines	650	280	330	330	500	350	350	2,790
● Agency								
Total	650	280	330	330	500	350	350	2,790
Program element performed by:								
● Agency Bureau of Mines	650	280	330	330	500	350	350	2,790
● Contractor								
● Other								
Total	650	280	330	330	500	350	350	2,790

SULFUR OXIDE CONTROL R&D AND RELATED PROGRAMS

Program IV FUEL CONVERSION	Program Element SULFUR CONTROL BY MEANS OF COAL GASIFICATION	Identification/Contract No. NCAPC-IV-F

Initiation date	Est. completion date	1st decision review	2nd decision review	Initial contract amount	Estimated total costs
January 1968	June 1969				$ 191,000

Bureau responsible National Center for Air Pollution Control	Sub organization CONTECH	Project director L. Stankus
Contractor or in-house organization performing work Scientific Research Instruments	Location of work Baltimore, Md.	

Technical description

A study of the kinetics of coal gasification (including coking and deep gasification) with emphasis on the sulfur balance of both pyritic and organic sulfur.

Utility/applicability

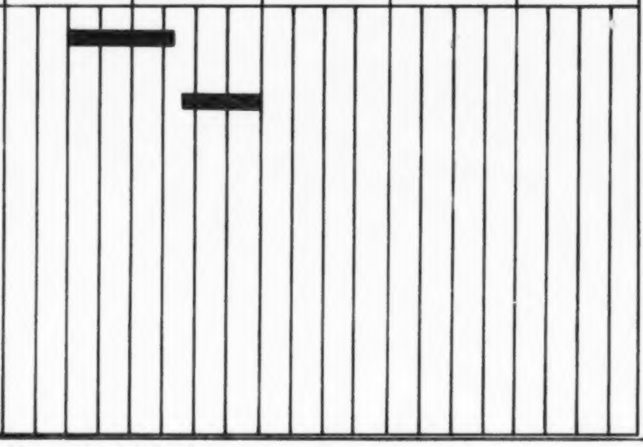
The project is intended to provide data for the evaluation of coal gasification processes.

Constraints to successful/on time completion

Other related or parallel R&D efforts

OCR projects on coal gasification.

Tasks	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 est. completion date	Post FY 72 cost
1. Laboratory study to trace sulfur in the gasification of coal.							
2. Laboratory study of the use of dolomite for removal of sulfur during gasification of coal.							



Funding--Obligated & estimated obligations required for future (thousands of dollars)

Fund source(s)	Total prior years	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 cost	Total cost
● Agency NCAPC	96		95					191
● Agency								
Total	96		95					191
Program element performed by:								
● Agency								
● Contractor Scientific Research Instruments	96		95					191
● Other								
Total	96		95					191

SULFUR OXIDE CONTROL R&D AND RELATED PROGRAMS

Program IV FUEL CONVERSION	**Program Element** SYNTHETIC PIPELINE GAS FROM COAL				**Identification/Contract No.** NCAPC-IV-G
Initiation date December 1963	**Est. completion date** September 1972	**1st decision review**	**2nd decision review**	**Initial contract amount** $1,956,000	**Estimated total costs** $11,425,000

Bureau responsible Office of Coal Research	**Sub organization** Utilization Division	**Project director** Cochran
Contractor or in-house organization performing work Bituminous Coal Research	**Location of work** Monroeville, Pa.	

Technical description

The contract seeks to develop a commercial process for producing pipeline gas (950 BTU/cu.ft.) from bituminus coal. The contractor is developing a "two-stage, super-pressure entrained gasifier" which, based on laboratory experiments, holds high promise for providing a competitive gasification plant. The laboratory experimental work during 1966, 1967 in a small reactor exceeded predicted results. A two-stage development scale reactor with auxilliary equipment under construction, is expected to provide data leading to a pilot plant during FY 69. If preliminary steps are successful, the commercial plant should be in production by 1975.

Utility/applicability

Commercial quality pipeline gas with very low sulfur. Alternatively, the process could produce a low cost fuel gas.

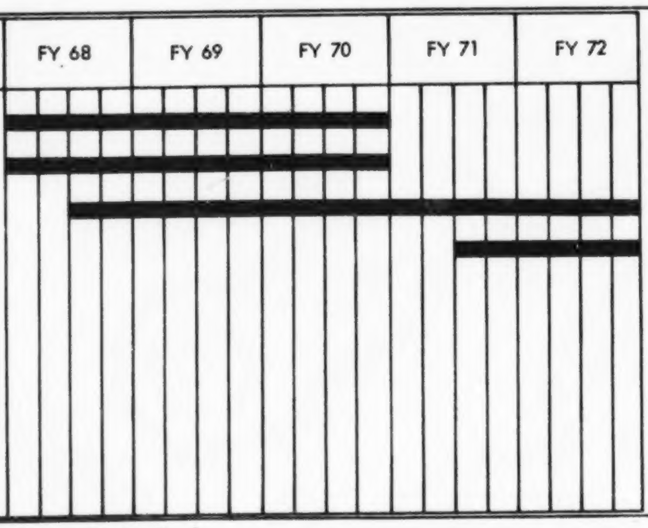
Constraints to successful/on time completion

The availability of funds and the successful development of a high pressure slagging gasifier for the bottom stage.

Other related or parallel R&D efforts

Hydrogasification (ICT); CO_2 Acceptor Gasification (Consolidated Coal); Molten Salt Process (Kellogg)

Tasks	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 est. completion date	Post FY 72 cost
1. Laboratory							
2. Bench scale							
3. Pilot plant							
4. Commercial design							



Funding--Obligated & estimated obligations required for future (thousands of dollars)

Fund source(s)	Total prior years	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 cost	Total cost
● Agency Office of Coal Research	1425	600	4000	2800	2200	400		11425
● Agency								
Total	1425	600	4000	2800	2200	400		11425
Program element performed by:								
● Agency								
● Contractor Bituminous Coal Research	1425	600	4000	2800	2200	400		11425
● Other								
Total	1425	600	4000	2800	2200	400		11425

SULFUR OXIDE CONTROL R&D AND RELATED PROGRAMS

Program IV FUEL CONVERSION	**Program Element** CATALYTIC METHANATION				**Identification/Contract No.** NCAPC-IV-H
Initiation date 1961	**Est. completion date** 1973	**1st decision review**	**2nd decision review**	**Initial contract amount**	**Estimated total costs** $2,250,000
Bureau responsible Bureau of Mines			**Sub organization**		**Project director**
Contractor or in-house organization performing work Bureau of Mines			**Location of work** Bruceton, Pa.		

Technical description

Process comprises production of synthesis gas from coal and its purification, followed by catalytic conversion. Pulverized caking coals are gasified with steam and oxygen at process pressure to produce a high methane content gas which is purified by conventional processes and then converted to methane. The methanation process utilizes Raney nickel catalyst flame-sprayed on tubular components of the reactor, through which a liquid coolant is circulated.

Utility/applicability

The product gas is a 950+ Btu gas interchangeable with commercial pipeline gas.

Constraints to successful/on time completion

Other related or parallel R&D efforts

Hydrogasification of coal.

Tasks	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 est. completion date	Post FY 72 cost
1. Bench scale	▬	▬					
2. Pilot plant			▬	▬	▬		
3. Prototype						FY 73	500,000

Funding--Obligated & estimated obligations required for future (thousands of dollars)

Fund source(s)		Total prior years	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 cost	Total cost
● Agency	Bureau of Mines	570	120	160	250	200	450	500	2250
● Agency									
	Total	570	120	160	250	200	450	500	2250
Program element performed by:									
● Agency	Bureau of Mines	570	120	160	250	200	450	500	2250
● Contractor									
● Other									
	Total	570	120	160	250	200	450	500	2250

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SULFUR OXIDE CONTROL R&D AND RELATED PROGRAMS

Program IV FUEL CONVERSION	**Program Element** PRODUCTION OF SYNTHETIC CRUDE OIL FROM COAL (GASOLINE)	**Identification/Contract No.** NCAPC-IV-I

Initiation date	**Est. completion date**	**1st decision review**	**2nd decision review**	**Initial contract amount**	**Estimated total costs**
August 1963	August 1972	August 1969		$15,200,000	$23,621,000

Bureau responsible Office of Coal Research	**Sub organization** Utilization Division	**Project director** Cochran
Contractor or in-house organization performing work Consolidation Coal Company	**Location of work** Library, Pa.; Cresup, W. Va.	

Technical description

Coal is largely dissolved in a coal derived solvent. Ash and non-reacted coal are removed by filtration and the extract hydrogenated to produce a low sulfur liquid refinery feed stock. A twenty-five ton/day (coal feed) pilot plant has been constructed in Cresup, W. Va. and is now undergoing shakedown operation. A new zinc chloride catalyst system has been developed in laboratory experiments, and when funds are available it will be incorporated in the pilot plant. The zinc chloride catalyst process promises a 10% reduction in the price of finished gasoline.

Utility/applicability

The availability, at competitive prices, of low sulfur liquid fuels (gasoline, furnace oil, LPG) made from sulfur containing coal.

Constraints to successful/on time completion

The availability of fuels; development of dependable methods for handling and filtering the coal extract; development of methods for handling and conserving massive amounts of zinc chloride catalyst.

Other related or parallel R&D efforts

Parallel projects are H-coal (Hydrocarbon Research, Inc.) and to some extent SEACOKE (ARCO) and COED (FMC) in that synthetic petroleum from coal is the common objective.

Tasks	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 est. completion date	Post FY 72 cost
1. Pilot plant	■	■	■	■	■		
2. Surveillance and evaluation	■	■	■	■			

Funding--Obligated & estimated obligations required for future (thousands of dollars)

Fund source(s)		Total prior years	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 cost	Total cost
● Agency	Office of Coal Research	9212	2625	3729	5225	2730	100		23621
● Agency									
	Total	9212	2625	3729	5225	2730	100		23621
Program element performed by:									
● Agency									
● Contractor	Consolidation Coal	9087	2500	3600	5100	2630	100		23017
●	Ralph M. Parsons Co.	125	125	129	125	100	0		604
	Total	9212	2625	3729	5225	2730	100		23621

SULFUR OXIDE CONTROL R&D AND RELATED PROGRAMS

Program IV FUEL CONVERSION	Program Element FLUIDIZED COKING OF RESID-COAL TO YIELD LIQUID AND SOLID BOILER FUEL (SEACOKE)	Identification/Contract No. NCAPC-IV-J

Initiation date	Est. completion date	1st decision review	2nd decision review	Initial contract amount	Estimated total costs
August 1964	May 1968			$918,000 *	$900,000

Bureau responsible	Sub organization	Project director
Office of Coal Research	Utilization Division	Cochran

Contractor or in-house organization performing work	Location of work
ARCO Chemical Co. Div. of Atlantic-Richfield	Philadelphia, Pa. and Princeton, N. J.

Technical description

Coal and residual oil are pyrolized in a fluidized bed. The overhead stream, after suitable catalytic hydrogeneration, is an acceptable refinery feed stock and the residual coke or char is boiler fuel for an adjacent power plant. The experimental work established that multiple stage pyrolysis was necessary to prevent agglomeration and the final proof of the process was done at the existing process development unit at FMC in Princeton, New Jersey. The final report, including a process design of a commercial scale unit, is now being prepared. Engineering estimates indicate that the process will be economically attractive in certain locations where there is an oil refinery power plant complex not far from coal supplies, such as East St. Louis, Illinois.

Utility/applicability

Constraints to successful/on time completion

The primary objective of the project was to substitute coal for petroleum and increase coal consumption. While the char-coke solid fuel is somewhat lower in sulfur than the feed materials, its removal was not a primary objective. However, the successful development of the FMC char sulfur removal system undoubtedly would be useful here.

Other related or parallel R&D efforts

Tasks	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 est. completion date	Post FY 72 cost
Laboratory	━━━━						

Funding--Obligated & estimated obligations required for future (thousands of dollars)

Fund source(s)	Total prior years	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 cost	Total cost
● Agency OCR	522	378						900
● Agency								
Total	522	378						900
Program element performed by:								
● Agency								
● Contractor ARCO Chemical Co.	522	378						900
● Other								
Total	522	378						900

* Initial contract amount authorized but not expended.

SULFUR OXIDE CONTROL R&D AND RELATED PROGRAMS

Program IV FUEL CONVERSION	Program Element H - COAL PROCESS	Identification/Contract No. NCAPC-IV-K

Initiation date	Est. completion date	1st decision review	2nd decision review	Initial contract amount	Estimated total costs
February 1965	June 1973			$2,064,000	$26,524,000

Bureau responsible Office of Coal Research	Sub organization Utilization Division	Project director Cochran
Contractor or in-house organization performing work Hydrocarbon Research, Inc.	Location of work Trenton, N. J.	

Technical description

Coal, in a slurry, is passed through an "ebullating bed" of catalyst in the presence of hydrogen. A substantial fraction of the coal (up to 30% MAF) is reacted and after subsequent treatment a low sulfur refinery feed stock is produced which can be converted into gasoline and other liquid fuels. A substantial quantity of experimental work, plus engineering evaluations of hypothetical full-scale plants, supports the feasibility of the process and a pilot plant has been proposed as the final stage of the work. However, because of lack of funds the contract has been terminated "without prejudice."

Utility/applicability

The availability of competitively priced low-sulfur liquid fuels (gasoline, furnace oil, etc.) produced from sulfur bearing coal. The process might be used to produce low-sulfur heating oil, only. Such oil could be used in existing power plants.

Constraints to successful/on time completion

Lack of funding

Other related or parallel R&D efforts

Project GASOLINE (Consolidation Coal), Project COED (FMC), Project SEACOKE (ARCO)

Tasks	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 est. completion date	Post FY 72 cost
1. Bench scale.	▬▬▬▬						
2. Pilot plant.	▬▬	▬▬▬▬	▬▬▬▬	▬▬▬▬	▬▬▬▬	FY 73	500,000

Funding--Obligated & estimated obligations required for future (thousands of dollars)

Fund source(s)		Total prior years	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 cost	Total cost
● Agency	OCR	1526	1248	8000	8250	3500	3500	500	26524
● Agency									
Total		1526	1248	8000	8250	3500	3500	500	26524
Program element performed by:									
● Agency									
● Contractor	Hydrocarbon Research	1526	1248	8000	8250	3500	3500	500	26524
● Other									
Total		1526	1248	8000	8250	3500	3500	500	26524

SULFUR OXIDE CONTROL R&D AND RELATED PROGRAMS

Program IV FUEL CONVERSION	**Program Element** CHAR-OIL ENERGY DEVELOPMENT	**Identification/Contract No** NCAPC-IV-L

Initiation date May 1962	**Est. completion date** March 1972	**1st decision review**	**2nd decision review**	**Initial contract amount** $7,670,490	**Estimated total costs** $12,707,000

Bureau responsible Office of Coal Research	**Sub organization** Utilization Division	**Project director** Cochran
Contractor or in-house organization performing work FMC Corporation	**Location of work** Princeton, N.J. and Pittsburgh, Pa.	

Technical description

This process subjects coal to three or four stages of fluidized bed pyrolysis at increasing temperatures starting at ~ 600° F and ending at ~ 1600° F. Three initial products are obtained, a solid char, a fuel gas, and a liquid or coal tar. The fuel gas is used to make hydrogen. The hydrogen is used to treat the liquid to make an acceptable petroleum refinery feed stock and remove sulfur from the char. Excess gas is available which can be converted to hydrogen for sale or sold as a fuel gas. The whole process then produces a low-sulfur synthetic crude, a low-sulfur solid fuel, a low-sulfur gas or hydrogen and elemental sulfur. Previous work has demonstrated technical feasibility of the basic process. The present work is to build and operate a pilot plant and further develop sulfur removal.

Utility/applicability

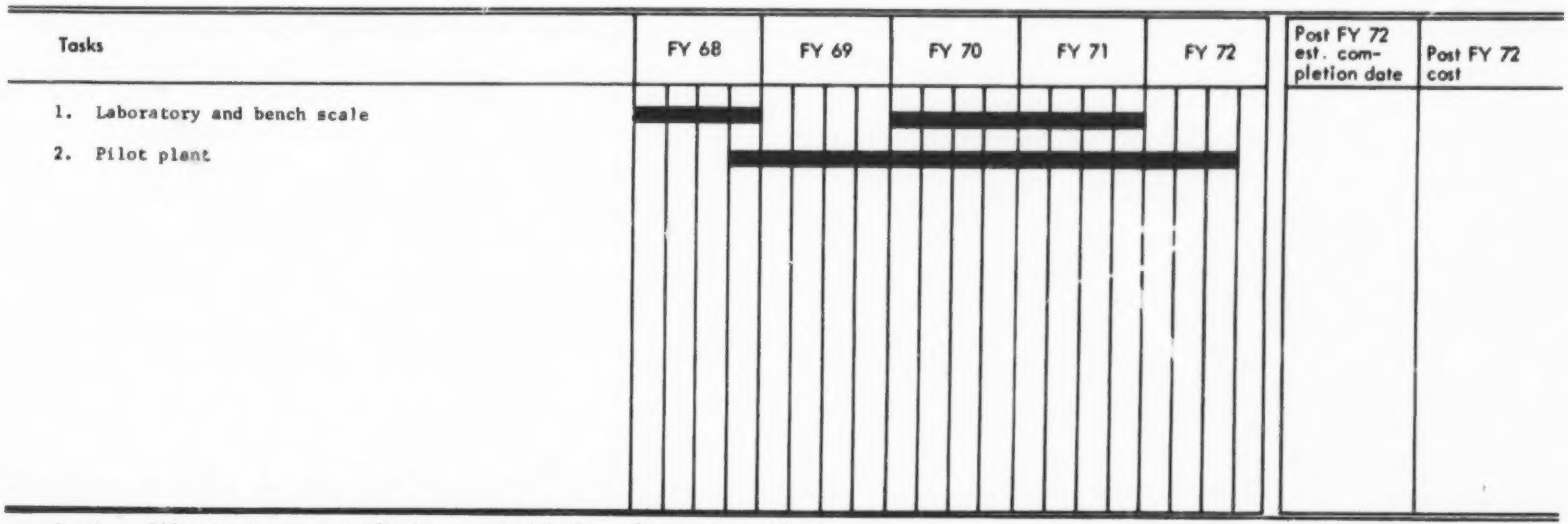
The end products will be three competitively priced low-sulfur fuels made from coal of normal- to high-sulfur content, and elemental sulfur.

Constraints to successful/on time completion

The availability of sufficient funding and the successful completion of laboratory development of the sulfur removal step.

Other related or parallel R&D efforts

The ARCO SEACOKE process was demonstrated in the FMC Process Development Unit. ARCO worked on methods to hydrogenate the FMC synthetic petroleum and evaluated the end product. The FMC sulfur removal system may be applicable to ARCO char or coke.



Funding--Obligated & estimated obligations required for future (thousands of dollars)

Fund source(s)	Total prior years	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 cost	Total cost
● Agency OCR	2134	725	4590	4050	1168	40		12707
● Agency								
Total	2134	725	4590	4050	1168	40		12707
Program element performed by:								
● Agency								
● Contractor FMC Corp	2134	725	4590	4050	1168	40		12707
● Other								
Total	2134	725	4590	4050	1168	40		12707

SULFUR OXIDE CONTROL R&D AND RELATED PROGRAMS

Program IV **FUEL CONVERSION**	**Program Element** LOW-ASH COAL	**Identification/Contract No.** NCAPC-IV-M

Initiation date	**Est. completion date**	**1st decision review**	**2nd decision review**	**Initial contract amount**	**Estimated total costs**
August 1962	June 1972	February 1965	June 1966	$1,140,000	$13,070,000

Bureau responsible Office of Coal Research	**Sub organization** Utilization Division	**Project director** Cochran
Contractor or in-house organization performing work Pittsburgh & Midway Coal Co.	**Location of work** Denver, Colo.; Kansas City, Mo., & Tacoma, Washington	

Technical description

Coal is dissolved in a coal derived solvent, filtered to remove ash, and reconstituted as an ash-free (~0.1%) low sulfur fuel with a heating value of about 16,000 BTU/lb. This project in its present stage is to design, build and operate a pilot plant (about 50 ton/day coal feed) to determine process variables and costs of the process with sufficient accuracy to permit the commercial application of the process by private industry. An additional purpose is to provide sufficient quantities of the product to develop the best burning methods. The technical feasibility of the process has already been demonstrated.

Utility/applicability

The product, either alone or diluted with light fuel oil, will provide a low cost, low sulfur fuel for diesel engines (locomotive or stationary) gas turbines, industrial plants, space heating, and some central station power plants.

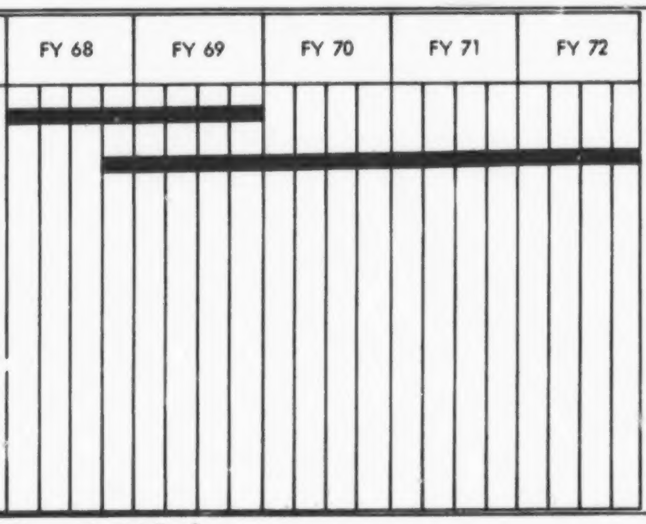
Constraints to successful/on time completion

The availability of sufficient funding: the availability of workable and reliable filters. Work on PROJECT GASOLINE has shown that excellent filters are within current "state of the art".

Other related or parallel R&D efforts

Possible future subcontract to develop commercial uses of solid residue. Future contract to develop process for making carbon and graphite electrodes from material. Future contracts, or subcontracts, to develop burning methods and equipment.

Tasks	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 est. completion date	Post FY 72 cost
1. Laboratory and bench scale.							
2. Pilot plant.							



Funding--Obligated & estimated obligations required for future (thousands of dollars)

Fund source(s)	Total prior years	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 cost	Total cost
● Agency OCR	1200	1400	3570	2500	2400	2000		13070
● Agency								
Total	1200	1400	3570	2500	2400	2000		13070
Program element performed by:								
● Agency								
● Contractor Pittsburgh and Midway Coal Company	1200	1400	3570	2500	2400	2000		13070
● Other								
Total	1200	1400	3570	2500	2400	2000		13070

SULFUR OXIDE CONTROL R&D AND RELATED PROGRAMS

Program IV FUEL CONVERSION	Program Element SOLVENT REFINED COAL	Identification/Contract No. NCAPC-IV-N

Initiation date July 1968	Est. completion date December 1968	1st decision review	2nd decision review	Initial contract amount	Estimated total costs $250,000

Bureau responsible National Center for Air Pollution Control	Sub organization CONTECH	Project director Spaite
Contractor or in-house organization performing work Unknown	Location of work Unknown	

Technical description

The Low-Ash Coal Process of Pittsburgh Midway Coal Mining Company, which is funded by OCR, is designed to remove only the ash and pyritic sulfur; however, by introducing proper amounts of hydrogen in the dissolving step, the organic sulfur can be removed as well. This combined process, then, is the only one which has the potential for removing both organic and pyritic sulfur from coal and consequently yielding a really low sulfur coal. Technical and economic evaluation are first needed to guide further development and support of this project by NCAPC.

Utility/applicability

A low sulfur coal $<$ .5% S can be produced from any coal except anthracite. The product will be a uniform fuel of high Btu content (16000 Btu/#). The uniform fuel will permit the use through the nation of a standard boiler design with low sulfur oxide emission. Transportation economies can also be realized.

Constraints to successful/on time completion

Other related or parallel R&D efforts

Low-Ash Coal Project (OCR)

Tasks	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 est. completion date	Post FY 72 cost
Technical and economic evaluation		▬					

Funding--Obligated & estimated obligations required for future (thousands of dollars)

Fund source(s)		Total prior years	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 cost	Total cost
● Agency	NCAPC			250					250
● Agency									
	Total			250					250
Program element performed by:									
● Agency									
● Contractor	Unknown			250					250
● Other									
	Total			250					250

SULFUR OXIDE CONTROL R&D AND RELATED PROGRAMS

Program IV FUEL CONVERSION	**Program Element** REFUSE AS A LOW SULFUR FUEL				**Identification/Contract No.** NCAPC-IV-O
Initiation date April 1968	**Est. completion date** April 1969	**1st decision review**	**2nd decision review**	**Initial contract amount** $150,000	**Estimated total costs** $150,000
Bureau responsible National Center for Air Pollution Control		**Sub organization** CONTECH		**Project director** Hangebrauch	
Contractor or in-house organization performing work Unknown		**Location of work** Unknown			

Technical description

A technical and economic evaluation of the potential of systems for utilizing refuse as a low-sulfur fuel for power generation will be developed.

Utility/applicability

The cost of disposing of refuse (by incineration or other means) is considerable. If the combustion of refuse (which is low in sulfur content) can be used to generate power, two objectives will be served.

Constraints to successful/on time completion

Other related or parallel R&D efforts

Tasks	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 est. completion date	Post FY 72 cost
Exploratory and feasibility study	▬	▬					

Funding--Obligated & estimated obligations required for future (thousands of dollars)

Fund source(s)	Total prior years	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 cost	Total cost
● Agency NCAPC		150						150
● Agency								
Total		150						150
Program element performed by:								
● Agency								
● Contractor Unknown		150						150
● Other								
Total		150						150

SULFUR OXIDE CONTROL R&D AND RELATED PROGRAMS

Program IV FUEL CONVERSION	Program Element UNDESIGNATED FUEL CONVERSION PROJECTS	Identification/Contract No. NCAPC-IV-P

Initiation date	Est. completion date	1st decision review	2nd decision review	Initial contract amount	Estimated total costs
July 1968	1973				$ 52,000,000

Bureau responsible National Center for Air Pollution Control	Sub organization CONTECH	Project director Spaite
Contractor or in-house organization performing work Various	Location of work Various	

Technical description

Experience has shown that many technically sound proposals, solicited and unsolicited, are received for process development. Noteworthy proposals may appear from either the government or private sector. The proposals may be in any one of the four stages of development or may require sequencing through each of the stages. This program element allows for future support of projects not yet known or defined. Once known and defined, a project will be funded from this program element and in later reports will be listed as a separate, totally defined program element with detailed planning funds. When similar proposals are received simultaneously from the private and government sectors, a comparative evaluation will be made and those considered most relevant to NCAPC's objectives will be selected. Because of the advanced state of the art of many fuel conversion processes, a large proportion of the funding is expected to be applied at the pilot and prototype scale.

Utility/applicability

Provides planning funds for implementing projects presently unknown or not yet clearly defined for evaluation. Work will provide for the conversion of sulfur-ladened fuels into new sulfur-free fuels.

Constraints to successful/on time completion

Funds are known to be required to support the general steps which are listed below as tasks and which are required for the development of any process. The exact quantity and distribution of funds cannot be prescribed nor specific time schedules assigned until detailed project proposals are submitted from all sectors and are objectively evaluated.

Other related or parallel R&D efforts

All those specifically defined in the Fuel Conversion Program.

Tasks	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 est. completion date	Post FY 72 cost
1. Exploratory and feasibility studies		■	■				
2. Laboratory and bench scale		■	■	■			
3. Pilot plant		■	■	■	■		
4. Prototype and/or demonstration		■	■	■	■		

Funding--Obligated & estimated obligations required for future (thousands of dollars)

Fund source(s)	Total prior years	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 cost	Total cost
● Agency NCAPC			7000	15000	15000	15000		52000
● Agency								
Total			7000	15000	15000	15000		52000
Program element performed by:								
● Agency								
● Contractor								
● Other Various Agencies and/or Contractors			7000	15000	15000	15000		52000
Total			7000	15000	15000	15000		52000

NEW COMBUSTION PROCESSES

PROGRAM V

F. Program V: New Combustion Processes

The Bureau of Mines and the Office of Coal Research have conducted work for years on new combustion processes. Their work has been directed toward broadening and conserving the resource base for coal. The aim of the new combustion processes has been improved efficiency in the conversion of heat to power. Some new combustion processes, such as the development of the fuel cell, provide pollution control by their very nature. Others may be modified to include SO_x control.

An example of the latter is found in the development of the fluidized bed combustion. Both OCR and the Bureau of Mines undertook development of the process for its high heat release and potential for improved efficiency of the process. The process would make coal a more desirable fuel for use in packaged industrial boilers or in electric utility boilers. Ash was the original material used in the fluidized bed. NCAPC suggested the use of dolomite as the fluidizing material so that SO_x could be removed in the bed as it is formed, thus eliminating the need for SO_x removal from the flue gas at a later stage. NCAPC and OCR have jointly funded the fluidized bed combustion process using dolomite materials in the bed.

Other new combustion approaches are possible. The production of the clean fuel may be integrated in the fuel combustion process. The wide variety of process possibilities which can be incorporated in combustion processes make this a large area for investigations with a great potential for control of SO_x. NCAPC is planning large scale research and development work for new combustion processes which yield virtually sulfur free emissions.

The NCAPC is planning to fund $22,212,000 for new combustion processes which are primarily oriented toward SO_x control. Of this amount, $22,000,000 is for projects not yet well enough defined to list at the project level. The remaining $212,000 will be NCAPC's portion of the funds in the cooperative work with OCR on fluidized bed combustion. The $22,000,000 will be utilized to fund the most worthy project proposals from the private and Government sectors. Most of the funds are expected to be used for large scale pilot and prototype development work.

The Bureau of Mines and the Office of Coal Research plan to fund a total of $1,300,000 and $30,809,000, respectively, for projects in new combustion sources, with the primary emphasis on broadening and conserving the resource base for coal through more efficient combustion methods. These programs may have collateral benefits which accrue to SO_x control. Thus, the total Federal program in new combustion processes with both primary and collateral SO_x control objectives is $54,321,000.

The distribution of the funds by funding agency and fiscal year is shown in Figure 11. The distribution by program elements and fiscal year of obligation is summarized in Figure 12. Funding according to source and performing agency is shown on the program element sheets that follow the figures.

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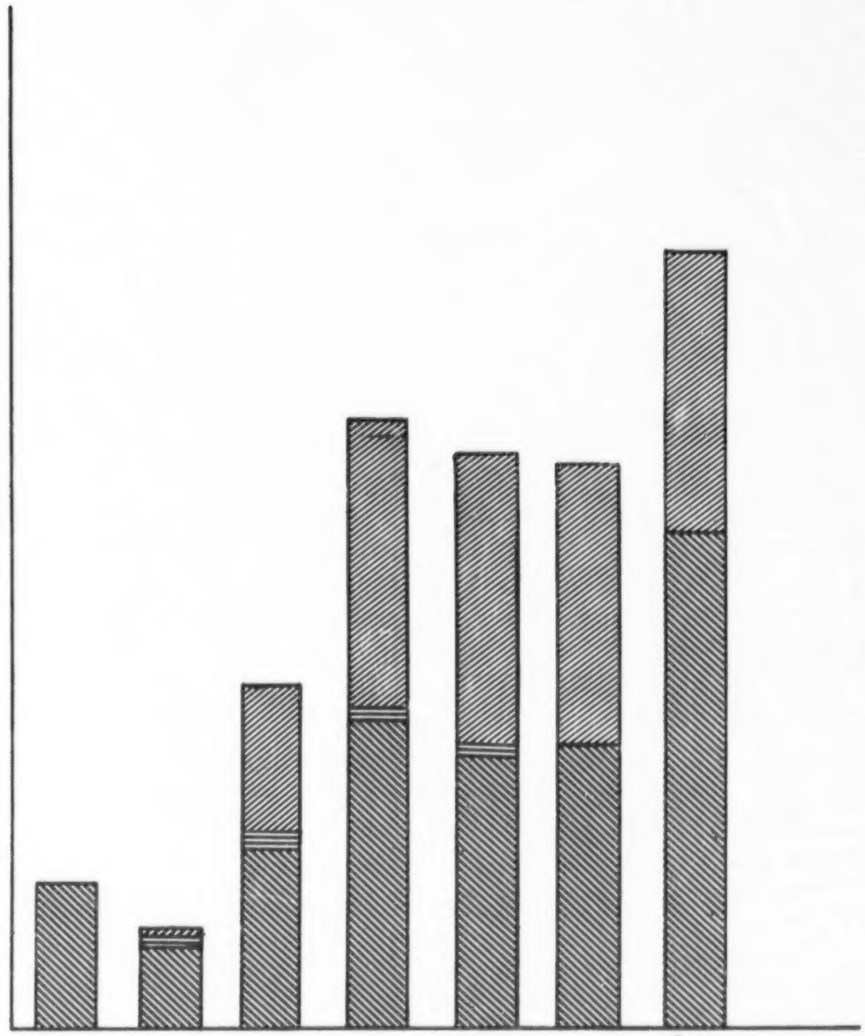
Figure 11

PROGRAM V. NEW COMBUSTION PROCESSES

By Funding Agency
(Thousands of Dollars)



	Funding Agencies	Prior FY 68	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72	Total
▨	NCAPC	0	60	2150	5002	5000	5000	5000	22212
▤	BuMines	0	375	370	260	295	0	0	1300
▧	OCR	2644	1425	3315	5250	4475	5000	8700	30809
░	TVA	0	0	0	0	0	0	0	0
■	FPC	0	0	0	0	0	0	0	0
	Total	2644	1860	5835	10512	9770	10000	13700	54321

3 OF 3

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180 769

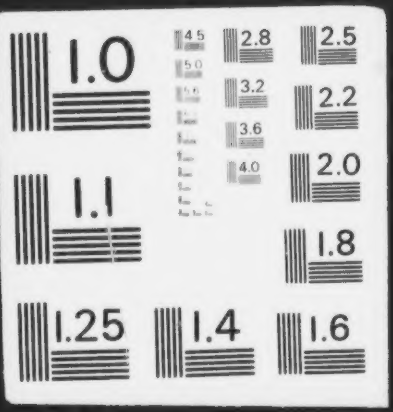
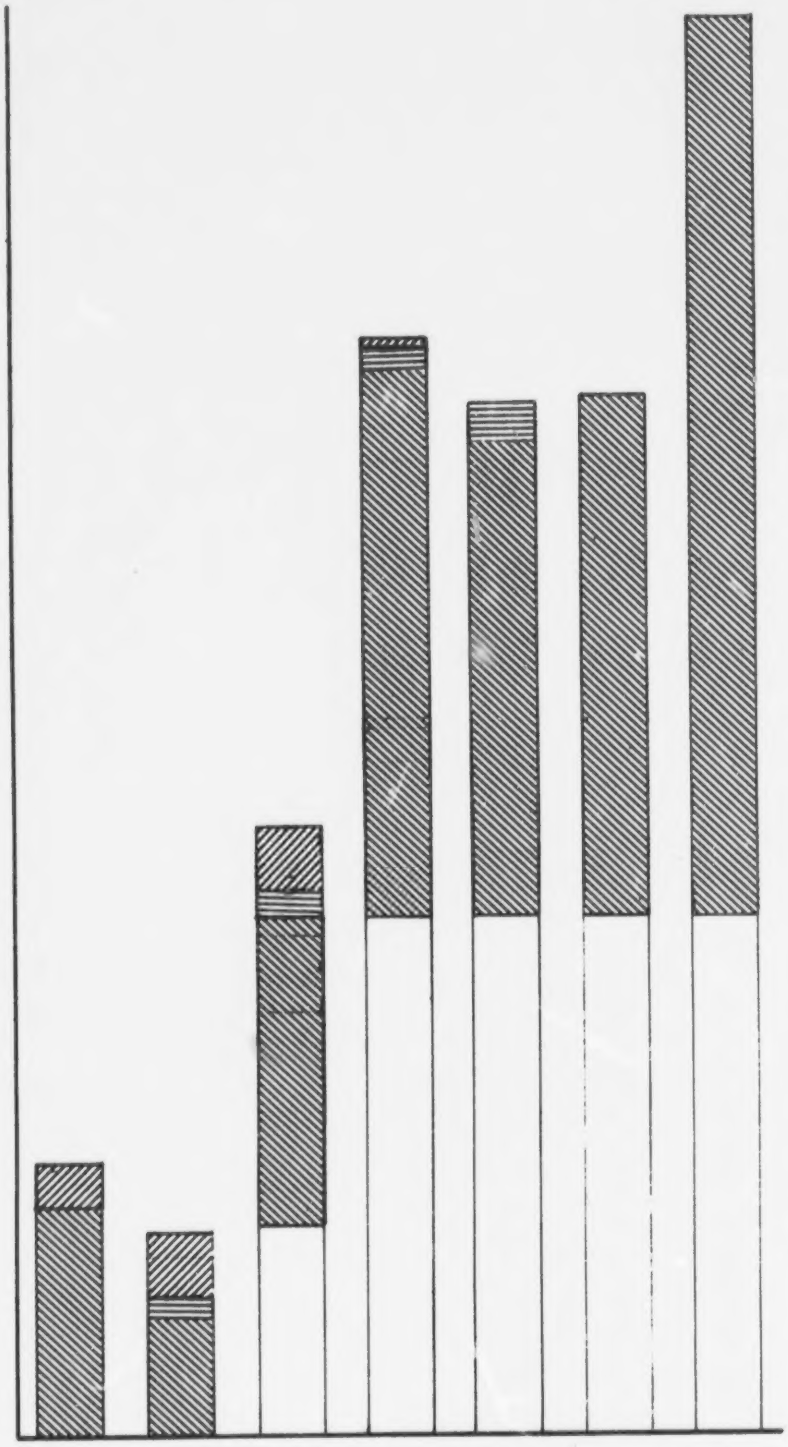

1.0
4.5
5.0
5.6
2.8
3.2
3.6
4.0
2.5
2.2
2.0
1.1
1.8
1.25
1.4
1.6

Figure 12

PROGRAM V. NEW COMBUSTION PROCESSES

By Program Element
(Thousands of Dollars)



	Program Elements	Prior FY 68	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72	Total	NCAPC Share of Total
▨	A. Fluidized Bed Combustion	444	500	585	52	0	0	0	1581	212
▤	B. Coal Conversion to Electricity	0	235	250	260	295	0	0	1040	0
▧	C. Fuel Cells	2200	**1125**	3000	5200	4475	5000	8700	29700	0
□	D. Undesignated Processes	0	0	2000	5000	5000	5000	5000	22000	22000
	Total	2644	1860	5835	10512	9770	10000	13700	54321	22212

SULFUR OXIDE CONTROL R&D AND RELATED PROGRAMS

Program V NEW COMBUSTION PROCESSES		Program Element FLUIDIZED BED COMBUSTION			Identification/Contract No. NCAPC-V-A
Initiation date February 1965	Est. completion date February 1970	1st decision review	2nd decision review	Initial contract amount	Estimated total costs $1,581,000

Bureau responsible National Center for Air Pollution Control, Office of Coal Research, and Bureau of Mines	Sub organization Mining and Preparation Division	Project director Hangebrauck (NCAPC), McCurdy (OCR), and Eckert (BuMines)
Contractor or in-house organization performing work Bureau of Mines and Pope, Evans, and Robbins	Location of work Alexandria, Virginia (OCR); Morgantown, West Virginia (BuMines)	

Technical description

Projects are directed toward developing practical designs for packaged and electric utility boilers using fluidized bed combustion. Coal and an inert bed of coal associated material is fluidized by blowing air jets through the bed in velocities sufficient to keep it in suspension. The coal is then burned in the presence of a minimum of excess air (stoichometric conditions), providing high heat release rates. OCR and Bureau of Mines projects differ in their design for high heat release. NCAPC's interest lies in controlling air pollution by using limestone or dolemite in the fluidized combustion bed to react with sulfur oxides released during coal combustion.

Utility/applicability

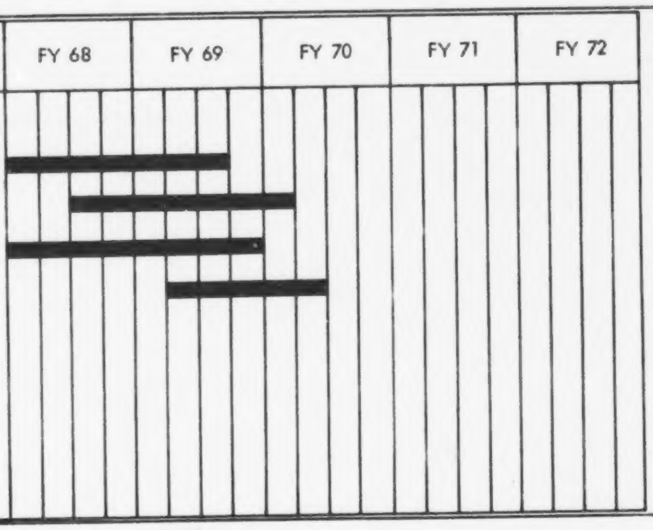
Coal fired boilers will be much smaller and cheaper to build and operate than at present. Carbon monoxide and nitrogen oxide will be non-existent in the stack gases, and sulfur dioxide will be drastically reduced, given success of the project. Higher boiler efficiency will reduce the fuel consumption per unit of steam or electricity.

Constraints to successful/on time completion

Possible lack of funds, difficulty in preventing excessive carbon loss, prevention of ash loss, automatic control of system, undetermined to date problems of operation, economic feasibility.

Other related or parallel R&D efforts

Tasks	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 est. completion date	Post FY 72 cost
1. Pilot plant							
a. High heat release (OCR)							
b. Sulfur oxide control (NCAPC)							
c. High heat release (Bureau of Mines)							
2. Design of commercial boilers (OCR)							



Funding--Obligated & estimated obligations required for future (thousands of dollars)

Fund source(s)	Total prior years	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 cost	Total cost
● Agency OCR	444	300	315	50				1109
● Agency NCAPC	0	60	150	2				212
Agency Bureau of Mines	0	140	120	0				260
Total	444	500	585	52				1581
Program element performed by:								
● Agency Bureau of Mines	0	140	120	0				260
● Agency								
● Contractor Pope, Evans, and Robbins	444	360	465	52				1321
Total	444	500	585	52				1581

SULFUR OXIDE CONTROL R&D AND RELATED PROGRAMS

Program V NEW COMBUSTION PROCESS	**Program Element** COAL CONVERSION TO ELECTRICITY	**Identification/Contract No.** NCAPC-V-B

Initiation date 1960	**Est. completion date** 1971	**1st decision review**	**2nd decision review**	**Initial contract amount**	**Estimated total costs** $1,040,000

Bureau responsible Bureau of Mines	**Sub organization** Various	**Project director** Various

Contractor or in-house organization performing work Bureau of Mines	**Location of work** Bruceton, Pa., Morgantown, W.Va., Grand Forks, N.D.

Technical description

Program is aimed at modification and improvement of current combustion practices to achieve lower emissions of sulfur oxides and other noxious emissions. Of particular interest is work on multi-purpose combustors and on improved combustion methods involving lignite and western coals.

Utility/applicability

Improvement can be applied to current combustion equipment.

Constraints to successful/on time completion

Other related or parallel R&D efforts

Tasks	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 est. completion date	Post FY 72 cost
1. Bench scale	━	━	━	━			
2. Pilot plant	━	━	━	━			

Funding--Obligated & estimated obligations required for future (thousands of dollars)

Fund source(s)	Total prior years	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 cost	Total cost
● Agency Bureau of Mines		235	250	260	295			1040
● Agency								
Total		235	250	260	295			1040
Program element performed by:								
● Agency Bureau of Mines		235	250	260	295			1040
● Contractor								
● Other								
Total		235	250	260	295			1040

SULFUR OXIDE CONTROL R&D AND RELATED PROGRAMS

Program V NEW COMBUSTION PROCESSES	Program Element FUEL CELLS	Identification/Contract No. NCAPC-V-C

Initiation date December 1962	Est. completion date June 1975	1st decision review	2nd decision review	Initial contract amount $2,397,000	Estimated total costs $29,700,000

Bureau responsible Office of Coal Research	Sub organization Utilization Division	Project director Cochran
Contractor or in-house organization performing work Westinghouse Electric Corporation	Location of work Pittsburgh, Pennsylvania	

Technical description

Solid state high temperature (1000° C) fuel cells supply heat directly to a fluidized bed of coal that is converted to H_2 and carbon oxide gases. These gases are cleaned and shifted before contacting the fuel electrode where they produce water favor and carbon dioxide. The oxygen electrode is contacted with heated air that is discharged through heat exchangers as nearly pure nitrogen. The proposed commercial plant is expected to produce high voltage DC current for transmission, and discharge products that are nearly pure nitrogen, ash, and heat.

Utility/applicability

Excess high purity water produced will supply cooling tower makeup and process steam. No contaminated products are discharged to the atmosphere and no water is required for process. The system has the potential of producing DC power at high voltage at a cost of 3.5 mills per kw or less.

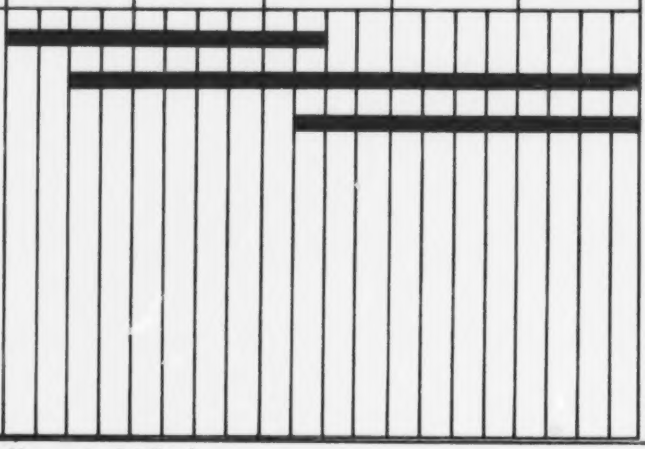
Constraints to successful/on time completion

Overall development cost is $28,700,000; funding delays could extend time for commercialization. Some new fabrication technology remains to be proven; success is dependent on solutions--particularly to fabrication methods.

Other related or parallel R&D efforts

Magnetogasdynamics (Gourdine, Inc.), Magnetohydrodynamics (AVCO), and Thermionic Topper (Consolidated Controls) are recognized as developments for a more efficient power cycle and, consequently, lower sulfur emissions per unit of power produced. Nevertheless they do have their own peculiar pollution problems and are not considered direct pollution control measures as fuel cells are with their clean emissions. MGD, MHD, and TT have not been included in this study.

Tasks	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 est. completion date	Post FY 72 cost
1. Feasibility and laboratory							
2. Bench scale (100 kw)							
3. Pilot plant (20 mw)						FY 75	



Funding--Obligated & estimated obligations required for future (thousands of dollars)

Fund source(s)	Total prior years	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 cost	Total cost
● Agency OCR	2200	1125	3000	5200	4475	5000	8700	29700
● Agency								
Total	2200	1125	3000	5200	4475	5000	8700	29700
Program element performed by:								
● Agency								
● Contractor Westinghouse	2200	1125	3000	5200	4475	5000	8700	29700
● Other								
Total	2200	1125	3000	5200	4475	5000	8700	29700

SULFUR OXIDE CONTROL R&D AND RELATED PROGRAMS

Program V NEW COMBUSTION PROCESSES	Program Element UNDESIGNATED NEW COMBUSTION PROCESSES	Identification/Contract No. NCAPC-V-D

Initiation date July 1968	Est. completion date June 1973	1st decision review	2nd decision review	Initial contract amount	Estimated total costs $22,000,000

Bureau responsible National Center for Air Pollution Control	Sub organization	Project director Paul Spaite
Contractor or in-house organization performing work Various	Location of work Various	

Technical description

New combustion processes which yield virtually sulfur-free emissions will be studied up through large-scale demonstration plants. New combustion processes may be modified for SO_x control, or novel new combustion processes with inherent control of the emission of sulfur oxides are expected to be developed. For example, the production of "clean" fuel may be efficiently and effectively integrated into the combustion process. Proposals are expected from both the government and private sectors. The most worthy will be funded as specific projects. Because of the advanced development of combustion technology, the work is expected to be large scale.

Utility/applicability

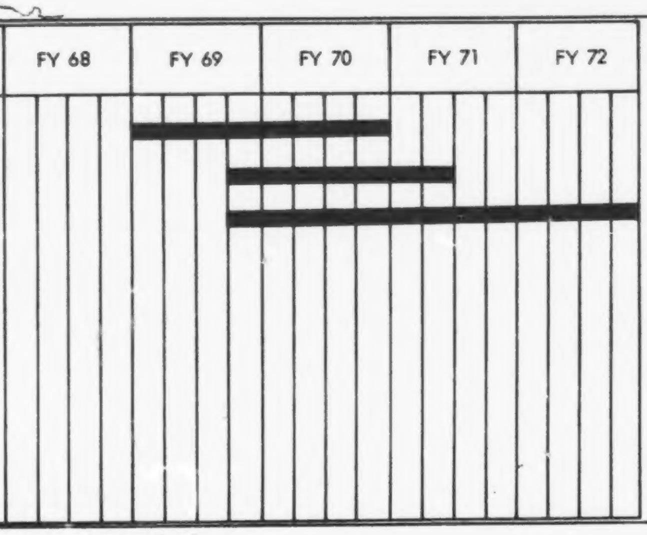
Development of certain new combustion processes provide a method of using high sulfur fuels without emissions of SO_x and with a recoverable sulfur byproduct. New combustion processes will be applicable to new intermediate and large-scale combustion systems utilizing fossil fuels.

Constraints to successful/on time completion

Lack of timely proposals with a potential for new sulfur-free combustion processes.

Other related or parallel R&D efforts

The fluidized bed combustion process using dolomite in the bed instead of ash is an example of a project similar to those expected to be developed in this program element.



Tasks	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 est. completion date	Post FY 72 cost
1. Feasibility studies and evaluation							
2. Large-scale pilot plant							
3. Prototype						FY 73	

Funding--Obligated & estimated obligations required for future (thousands of dollars)

Fund source(s)	Total prior years	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 cost	Total cost
● Agency NCAPC			2000	5000	5000	5000	5000	22,000
● Agency								
Total								
Program element performed by:								
● Agency NCAPC *			2000	5000	5000	5000	5000	22,000
● Contractor								
● Other								
Total			2000	5000	5000	5000	5000	22,000

* These funds are available for contract or transfer to other agencies dpending upon comparative analysis of proposals.

PROGRAM VI

INDUSTRIAL PROCESS CONTROL

G. Program VI: Industrial Process Control

The SO_x control problems of the public utilities have been relatively well documented. However, other sources of sulfur oxides account for over half the estimated emission, and their control problems are not well defined. Most of these emissions come from various industrial sources, including both combustion and noncombustion types. Included among these are nonferrous smelting, coke manufacturing, integrated iron and steel mills, sulfuric acid producers, petroleum refineries, pulp and paper manufacturers, and industrial and commercial boilers for various uses. Control of these sources may call for methods substantially different from those applicable to power plants.

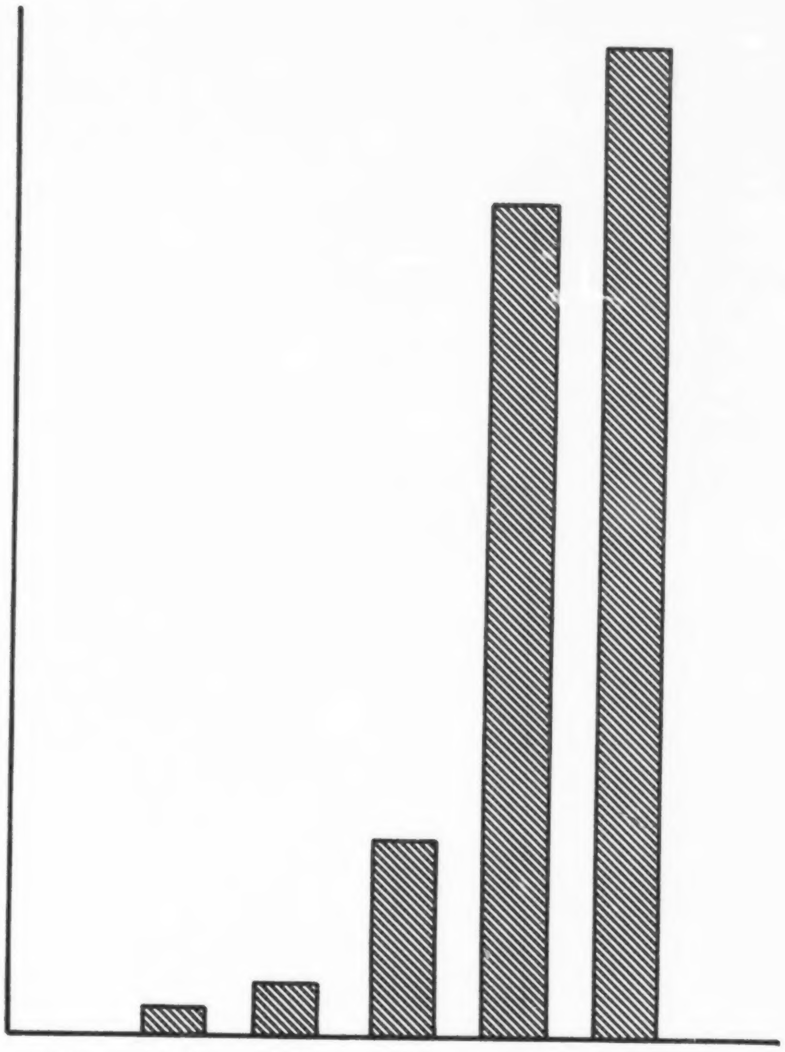
In an effort to encourage more extensive control of sources such as primary smelters, pulp and paper mills, sulfuric acid plants, and coke plants, NCAPC is planning to support a series of cooperative studies. The first step will consist of contracts for systems studies to define the problems of sulfur pollution control in the several industries. The objective is to determine research and development needs and to establish industrial contacts to provide consultation and active participation in jointly sponsored research. The first such activity at the project level is with Arthur McKee Company and involves the study of primary smelters. Similar studies of the pulp and paper industry and the iron and steel industry are in advanced planning stages. These initial studies will lead to large scale cooperative developments for the control of sulfur emissions.

The total funding planned for Program VI, Industrial Process Control, is \$65,732,000, all of which is directly related to the development of SO_x control technology. Only \$1,882,000 is designated at the project level at this time. The work will be conducted by various contractors. The balance of \$63,850,000 is curently undesignated at the project level and is available for contract or transfer to Government agencies upon comparative analysis of specific project proposals. A large portion of these funds is expected to be utilized to fund the scale-up of SO_x control processes in the various industries. The distribution of funds by program element and fiscal year of planned obligation is shown in Figure 13. The program element and supplementary data sheets following the figure present detailed data, including planned distribution of funds by source and performing group.

Figure 13

PROGRAM VI. INDUSTRIAL PROCESS CONTROL

By Program Element*
(Thousands of Dollars)



Program Element	Prior FY 68	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72	Total
▨ A. Non-Utility Control Processes (General)	0	882	1700	6150	26000	31000	0	65732
Total	0	822	1700	6150	26000	31000	0	65732

* All funds provided by NCAPC.

SULFUR OXIDE CONTROL R&D AND RELATED PROGRAMS

Program VI INDUSTRIAL PROCESS CONTROL	Program Element NON-UTILITY CONTROL PROCESSES (GENERAL)	Identification/Contract No. NCAPC-VI-A

Initiation date July 1967	Est. completion date Indefinite	1st decision review	2nd decision review	Initial contract amount	Estimated total costs $30,732,000

Bureau responsible National Center for Air Pollution Control	Sub organization CONTECH	Project director D. R. Monti
Contractor or in-house organization performing work Various	Location of work Various	

Technical description

The program consists of systems studies of air pollution from various industrial sources of SO_x emission, other than utilities, i.e., non-ferrous smelting, coke manufacturing, integrated iron and steel, sulfuric acid, petroleum refining, pulp and paper, industrial and commercial boilers. Each study consists of a comprehensive survey of the industry concerned, the emissions from it, the process technology as related to air pollution, and the state of the art of air pollution control in the industry. These studies may proceed through each of the four tasks shown below, although this is unlikely. At each task completion, a review, analysis, and decision to proceed or cancel will be made. The amounts for each task are estimated requirements for each year without regard to a specific area. The amounts in a specific area are actual known values to a decision point. See following page for additional information on those studies which have already been specified. Other studies will be specified in the future. Funding for these is provided.

Utility/applicability

Sources other than public utilities account for over half of the total SO_x emission. Most of this emission comes from various industrial sources, including both combustion and non-combustion sources. Appropriate methods must be developed to control emissions from these sources, and may be substantially different from the controls being developed for use by utilities.

Constraints to successful/on time completion

Other related or parallel R&D efforts

Tasks	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 est. completion date	Post FY 72 cost
1. Industrial surveys and control feasibility studies		■	■				
2. Exploratory and supporting bench scale studies		■	■	■	■		
3. Pilot plant studies			■	■	■		
4. Prototype and demonstration studies in cooperation with industry				■	■		

Funding--Obligated & estimated obligations required for future (thousands of dollars)

Fund source(s)		Total prior years	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 cost	Total cost
● Agency	NCAPC		882	1700	6150	26000	31000		65732
● Agency									
	Total		882	1700	6150	26000	31000		30732
Program element performed by:									
● Agency	NCAPC *		0	700	6150	26000	31000		63850
● Contractor	Various		882	1000	0	0	0		1882
● Other									
	Total		882	1700	6150	26000	31000		65732

* These funds are available for contract or transfer to agency dependent upon comparative analysis of proposals in specific areas.

SULFUR OXIDE CONTROL R&D AND RELATED PROGRAMS

Program VI	Program Element	Identification/Contract No.
INDUSTRIAL PROCESS CONTROL	NON-UTILITY CONTROL PROCESSES (GENERAL)	NCAPC-VI-A

Supplementary data and comments

Industrial surveys and control feasibility studies (Task I) comprising a state of the art survey, an inventory of emissions, an analysis of existing and potential technology for SO_x control and applicable market analyses have been designated for the following:

Project	Task Status	Executing Contractor or Agency	Funding Source and Amount	Date	
				Start	Complete
Non-Ferrous Smelting Industry a. Survey of Primary Copper, Lead and Zinc Smelting	1	Arthur G. McKee	NCAPC $382,000	Jan 68	Jan 69
Coke Manufacturing Industry Survey a. Survey of By-product and Beehive Coke Ovens for Pollution Control	1	Unknown	NCAPC $250,000	FY 69	
Integrated Iron and Steel a. Survey of Integrated Iron & Steel Mills	1	Unknown	NCAPC $250,000	FY 68	
Sulfuric Acid a. Survey of Sulfuric Acid Industry for SO_2 Emissions Control	1	Unknown	NCAPC $250,000	FY 69	
Petroleum Refining Industry a. Survey Petroleum Refining System for Optimum SO_2 Emission Control	1	Unknown	NCAPC $250,000	FY 69	
Pulp and Paper Manufacturing a. Survey of Pulp and Paper Air Pollution Problem and Control Development Needs	1	Unknown	NCAPC $250,000	FY 68	
Industrial and Commercial Boilers a. System Analysis of Control Methods for Stationary Combustion Units	1	Unknown	NCAPC $250,000	FY 69	

PROGRAM VII

FUEL AVAILABILITY SURVEYS

H. Program VII: Fuel Availability Surveys

At the present time, the principal method used to curtail sulfur oxide emissions from combustion sources is the substitution of fuels naturally low in sulfur, and this situation will probably persist over a period of several years. Hence, it is imperative that there be adequate information on the availability of naturally occurring low-sulfur fuels. The Bureau of Mines is currently carrying out for NCAPC a survey of the availability of low-sulfur coal. The cost of the survey is being borne by both agencies.

In addition, the Federal Power Commission and the NCAPC are jointly undertaking studies and analyses of known foreign and domestic natural gas supplies, air quality control regional gas demands, and the economics and technology of transportation and storage of liquefied natural gas.

The magnitude of the problem and the urgent need for the results requires the recruitment of all available capabilities for work in important fuel supply regions of the nation. Needs have not yet been satisfied, and provision is made in the program element sheet entitled, "Undesignated Fuel Availability Surveys" for additional projects to be conducted by contractors or other Government agencies.

The NCAPC plans to fund a total of $4,387,000 for fuel availability studies which have SO_x control as their primary objective. These funds are assigned to contractors or transferred to the Bureau of Mines and the Federal Power Commission as performing agencies. These agencies plan to fund a total of $3,301,000 in the performance of the cooperative effort with NCAPC. The Office of Coal Research plans to fund $1,549,000 under contract to Penn State for fuel availability surveys for coals most suited for boiler use and also amenable to new and practical methods of removing sulfur. The work is expected to be of collateral benefit to the control of SO_x.

The distribution of funding by sources of funds and fiscal years is shown in Figure 14. It is interesting to note that funding by NCAPC tapers off after FY 70, and funding by Bureau of Mines increases. This transfer of emphasis is natural as the Bureau incorporates the sulfur requirements for SO_x control activities into its continuing program on the availability of fuels.

The distribution of funds by program element and fiscal year is summarized in Figure 15. Distribution of funds by source and performing agency is shown, along with other detailed data, on program element sheets NCAPC-VII-A, B, C, D, E, and F.

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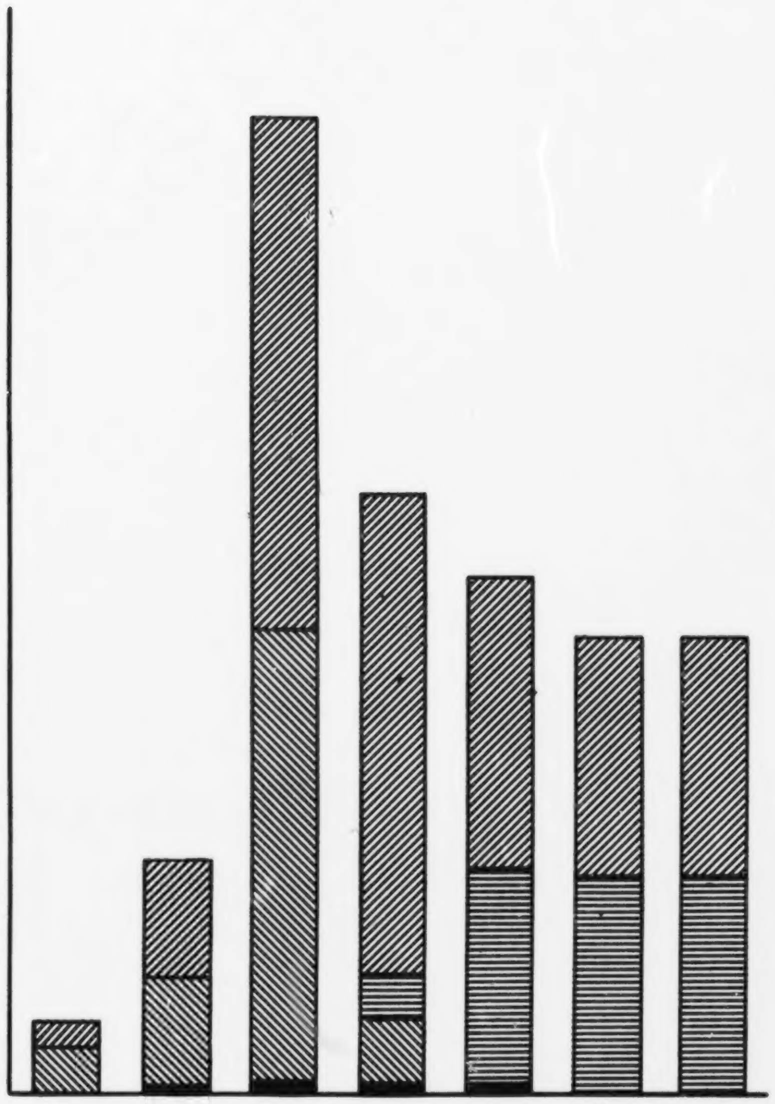
Figure 14

PROGRAM VII. FUEL AVAILABILITY SURVEYS

By Funding Agency
(Thousands of Dollars)



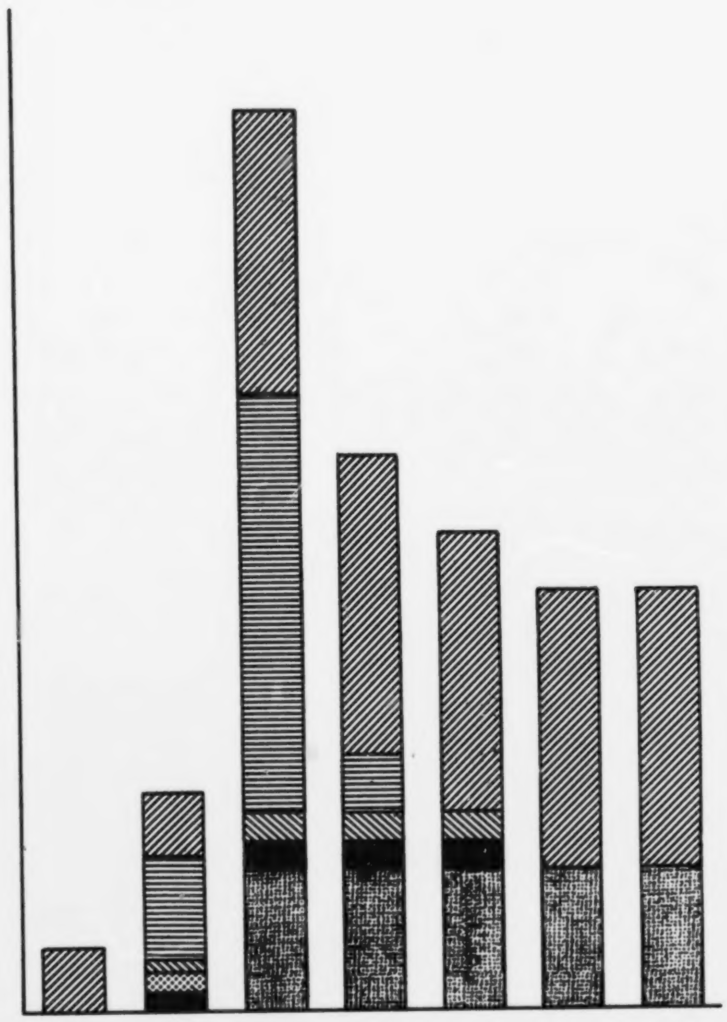
Funding Agencies

		Prior FY 68	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72	Total
▨	NCAPC	55	272	1180	1110	670	550	550	4387
▤	BuMines	0	76	76	100	500	500	500	1752
▧	OCR	105	254	1040	150	0	0	0	1549
▩	TVA	0	0	0	0	0	0	0	0
■	FPC	0	10	20	20	20	0	0	70
	Total	160	612	2316	1380	1190	1050	1050	7758

Figure 15

PROGRAM VII. FUEL AVAILABILITY SURVEYS

By Program Element
(Thousands of Dollars)



	Program Elements	Prior FY 68	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72	Total	NCAPC Share of Total
▨	A. Availability of Low-Sulfur Coal	55	228	786	740	700	700	700	3909	2157
☰	B. Development of Special Purpose Coals	105	254	1040	150	0	0	0	1549	0
▧	C. Availability of Natural Gas As Substitute for Low Sulfur Fuel	0	30	70	70	70	0	0	240	170
▒	D. Technology and Availability of Liquified Natural Gas	0	50	0	0	0	0	0	50	50
■	E. Availability of Various Grades of Oil for Different Idealized Refining Modes	0	50	70	70	70	0	0	260	260
▓	F. Undesignated Fuel Availability	0	0	350	350	350	350	350	1750	1750
	Total	160	612	2316	1380	1190	1050	1050	7758	4387

SULFUR OXIDE CONTROL R&D AND RELATED PROGRAMS

Program VII FUEL AVAILABILITY SURVEYS	**Program Element** AVAILABILITY OF LOW SULFUR COAL	**Identification/Contract No.** NCAPC-VII-A

Initiation date 1968	**Est. completion date** 1973	**1st decision review** 1969	**2nd decision review**	**Initial contract amount**	**Estimated total costs** $3,909,000

Bureau responsible National Center for Air Pollution Control	**Sub organization**	**Project director** Scollon
Contractor or in-house organization performing work Bureau of Mines	**Location of work**	

Technical description

By personal canvass of representatives of coal-mining companies and by correlation with in-house data of the U.S. Geological Survey, State Geological Surveys, and others develop a record of coal reserves, by ranges of sulfur content, in those counties in which low-sulfur coals predominate, principally in the Appalachian region, with initial concentration in southern Appalachia, where the greatest potential availabilities are considered to occur; and simultaneously canvass the coal industry, by questionnaire, regarding its productive capacity in relation to the availability of low-sulfur coals; to tabulate analyses of coals by sulfur content and related factors; to estimate delivered costs (including production and transportation); and to conduct impact studies (economic and social) in selected areas.

Utility/applicability

Guide producers, consumers, and public authorities with respect to the availability of coals of various sulfur levels, particularly low-sulfur coals, to meet air pollution standards through the use of low-sulfur coals.

Constraints to successful/on time completion

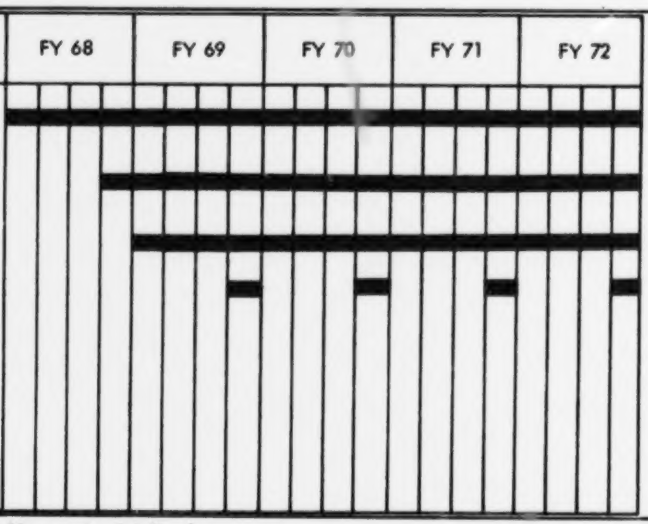
Cooperation of the individual mining, land-holding, and railroad companies.

Other related or parallel R&D efforts

The Bureau of Mines is conducting a similar investigation of coals used in the coke and steel industries. Also, the Bureau regularly collects analyses of coals, including sulfur content and other quality characteristics of coal, in connection with certifications of coal quality for purchase by Federal agencies.

Tasks

1. Collect data
2. Analyze data for reserves by sulfur content and estimated delivered costs
3. Analyze data for economic and social impact in selected areas
4. Prepare report



Post FY 72 est. completion date	Post FY 72 cost
FY 73	

Funding--Obligated & estimated obligations required for future (thousands of dollars)

Fund source(s)	Total prior years	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 cost	Total cost
● Agency NCAPC	55	152	710	640	200	200	200	2157
● Agency Bureau of Mines	0	76	76	100	500	500	500	1752
Total	55	228	786	740	700	700	700	3909
Program element performed by:								
● Agency NCAPC	0	0	300	300	200	200	200	1200
● Agency Bureau of Mines	55	228	486	440	500	500	500	2709
● Other								
Total	55	228	786	740	700	700	700	3909

SULFUR OXIDE CONTROL R&D AND RELATED PROGRAMS

Program VII FUEL AVAILABILITY SURVEYS	**Program Element** DEVELOPMENT OF SPECIAL PURPOSE COALS	**Identification/Contract No.** NCAPC-VII-B

Initiation date	**Est. completion date**	**1st decision review**	**2nd decision review**	**Initial contract amount**	**Estimated total costs**
September 1966	January 1970				$1,549,000

Bureau responsible	**Sub organization**	**Project director**
Office of Coal Research	Division of Mining & Preparation	McCurdy

Contractor or in-house organization performing work	**Location of work**
Pennsylvania State University	State College, Pennsylvania; numerous coal mines

Technical description

Whole coal seam samples and petrographic coal lithotypes are collected from mines all over the United States. These are chemically, physically, and petrographically classified and evaluated in an effort to determine what coals and what coal compositions are most suited for boiler plant uses. Then efforts will be made to develop new and practical methods of removing sulfur and separating the various coal lithotypes for these special purposes.

Utility/applicability

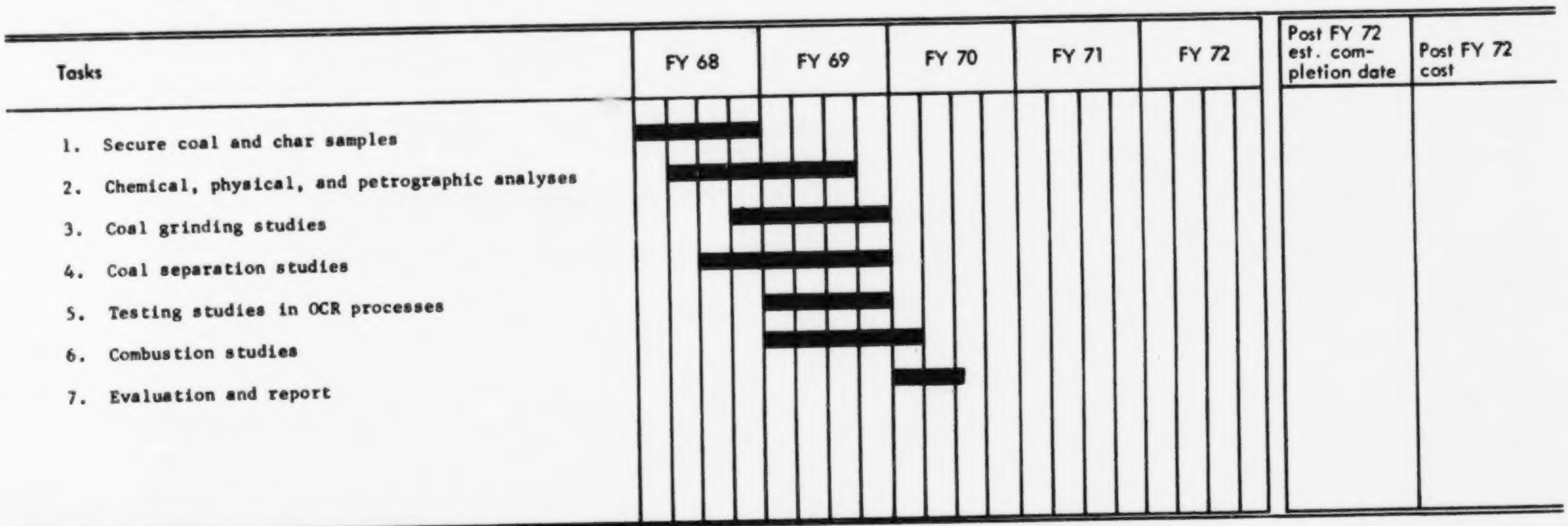
The project may greatly improve the technical and economic feasibility of a number of other OCR projects for the conversion of coal to cleaner and more convenient forms, thus reducing air pollution from solid fuels, as well as directly reducing the sulfur content of coal used in conventional forms.

Constraints to successful/on time completion

Potential shortage of funds and degree of sophistication and cost of the separation and preparation techniques found to be effective.

Other related or parallel R&D efforts

Sewage treatment process (The RAND Corp.); coal-fired diesel (Howard University); all OCR projects related to the conversion of coal to liquids and gases.



1. Secure coal and char samples
2. Chemical, physical, and petrographic analyses
3. Coal grinding studies
4. Coal separation studies
5. Testing studies in OCR processes
6. Combustion studies
7. Evaluation and report

Funding--Obligated & estimated obligations required for future (thousands of dollars)

Fund source(s)	Total prior years	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 cost	Total cost
● Agency Office of Coal Research	85	225	1040	150				1500
● Agency (Penn State University)	20	29	(FOR PURCHASE OF SPECIAL EQUIPMENT)					49
Total	105	254	1040	150				1549
Program element performed by:								
● Agency								
● Contractor Penn State University	105	254	1040	150				1549
● Other								
Total	105	254	1040	150				1549

SULFUR OXIDE CONTROL R&D AND RELATED PROGRAMS

Program VII FUEL AVAILABILITY SURVEYS	Program Element AVAILABILITY OF NATURAL GAS AS A SUBSTITUTE FOR LOW SULFUR FUEL	Identification/Contract No. NCAPC-VII-C

Initiation date	Est. completion date	1st decision review	2nd decision review	Initial contract amount	Estimated total costs
June 1968	June 1971	July 1969	July 1970	$20,000	$240,000

Bureau responsible National Center for Air Pollution Control	Sub organization Abatement and Control Programs	Project director M. Dean High
Contractor or in-house organization performing work Federal Power Commission	Location of work Washington, D. C.	

Technical description

An econometric model is now being constructed by FPC to resolve questions of gas supply and demand at different price levels. National Center for Air Pollution Control support of this project will accelerate the project and lay the groundwork for application of the findings to gas demands created by air pollution control needs. A second portion of the project is to analyze specific air quality control regions or metropolitan areas in terms of existing gas supply and price, cost of incremental quantities of gas, likely sources of supply, and projected markets for the next ten years. A pilot study of one area would develop the format which would be applied later to ten designated areas per year in different regions of the country.

Utility/applicability

The project will provide information on the potential availability and cost of natural gas to meet new or expanded markets created by air pollution control needs and regulations.

Constraints to successful/on time completion

Other related or parallel R&D efforts

Projects on availability of low sulfur coal, low sulfur oil, and atomic energy.

Tasks	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 est. completion date	Post FY 72 cost
1. Develop an estimate of the equations for natural gas demand	▬	▬					
2. Prepare a more comprehensive model of supply, transport and demand of natural gas		▬	▬	▬			
3. Analyze thoroughly one air quality control region in terms of natural gas demand, etc.		▬					
4. Apply the format to other selected areas of the nation		▬	▬	▬			

Funding--Obligated & estimated obligations required for future (thousands of dollars)

Fund source(s)		Total prior years	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 cost	Total cost
● Agency	NCAPC		20	50	50	50			170
● Agency	FPC		10	20	20	20			70
Total			30	70	70	70			240
Program element performed by:									
● Agency	FPC		30	70	70	70			240
● Contractor									
● Other									
Total			30	70	70	70			240

SULFUR OXIDE CONTROL R&D AND RELATED PROGRAMS

Program VII FUEL AVAILABILITY SURVEYS	**Program Element** TECHNOLOGY AND AVAILABILITY OF LIQUIFIED NATURAL GAS	**Identification/Contract No.** NCAPC-VII-D

Initiation date July 1968	**Est. completion date** June 1969	**1st decision review**	**2nd decision review**	**Initial contract amount**	**Estimated total costs** $50,000

Bureau responsible National Center for Air Pollution Control	**Sub organization** Abatement and Control Programs	**Project director** M. Dean High
Contractor or in-house organization performing work Unknown	**Location of work** Washington, D. C.	

Technical description

The purpose of this project is to review and summarize the state of the art for commercially liquefying natural gas. This study would include analyses of known foreign and domestic gas supplies, as well as transportation, storage, and economic considerations for developing this technology.

Utility/applicability

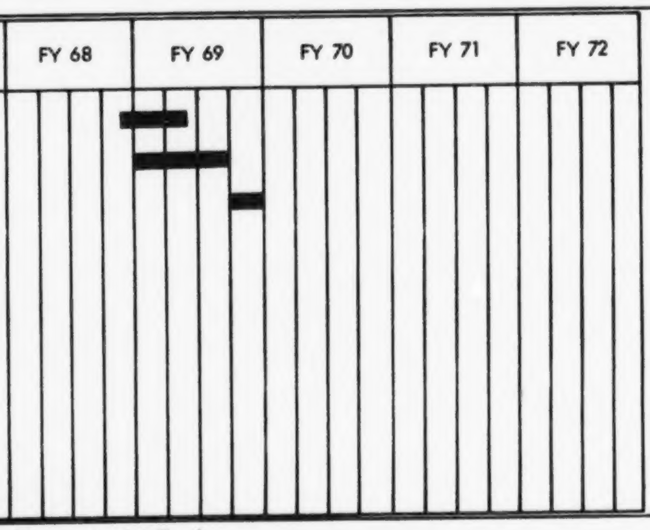
Results of this project will determine the quantity and cost of additional gas reserves that likely will be developed to supplement natural gas now available as a substitute fuel for air pollution control needs.

Constraints to successful/on time completion

Other related or parallel R&D efforts

Other new technologies for energy development such as fuel oil from shale reserves or coal liquefaction or gasification.

Tasks	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 est. completion date	Post FY 72 cost
1. Collect data							
2. Analyze data							
3. Prepare report							



Funding--Obligated & estimated obligations required for future (thousands of dollars)

Fund source(s)	Total prior years	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 cost	Total cost
● Agency NCAPC		50						50
● Agency								
Total		50						50
Program element performed by:								
● Agency NCAPC		50						50
● Contractor								
● Other								
Total		50						50

SULFUR OXIDE CONTROL R&D AND RELATED PROGRAMS

Program VII FUEL AVAILABILITY SURVEYS	**Program Element** AVAILABILITY OF VARIOUS GRADES OF OIL FOR DIFFERENT IDEALIZED REFINING MODES	**Identification/Contract No.** NCAPC-VII-E

Initiation date June 1968	**Est. completion date** June 1971	**1st decision review**	**2nd decision review**	**Initial contract amount** $50,000	**Estimated total costs** $260,000

Bureau responsible National Center for Air Pollution Control	**Sub organization** Abatement and Control Programs	**Project director** M. Dean High

Contractor or in-house organization performing work Unknown	**Location of work** Unknown

Technical description

Develop a general model which relates supply, demand, and price of various grades of oil. The supply portion of the model will delineate the output and cost of various grades of oil under different idealized refining modes at each major producing area of the world. The demand portion will define the demand and price of various grades of oil for each of the nation's air quality regions. Constraints will be applied to the general model to determine their effect on the availability of low sulfur oils in the nation's air quality regions.

Utility/applicability

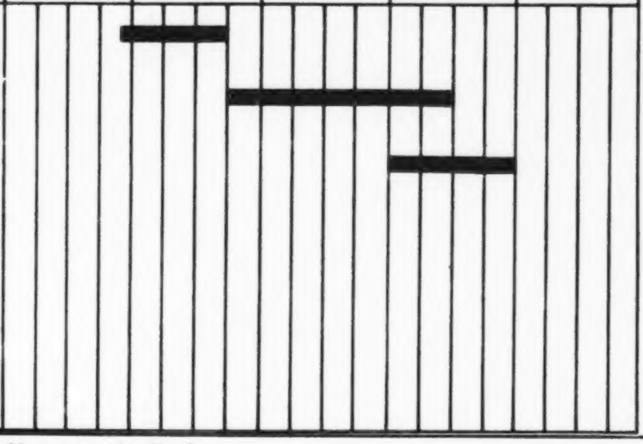
Information developed will establish the potential availability and cost of various grades of oil to meet market conditions created by air pollution control requirements and regulations.

Constraints to successful/on time completion

Other related or parallel R&D efforts

Projects on availability of low sulfur coal, natural gas, liquified natural gas, and atomic energy.

Tasks	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 est. completion date	Post FY 72 cost
1. Develop general model							
2. Develop realistic constraints and determine their effect on availability of low sulfur oils							
3. Develop summary report on availability of low sulfur oils							



Funding--Obligated & estimated obligations required for future (thousands of dollars)

Fund source(s)	Total prior years	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 cost	Total cost
● Agency NCAPC		50	70	70	70			260
● Agency								
Total		50	70	70	70			260
Program element performed by:								
● Agency								
● Contractor Unknown		50	70	70	70			260
● Other								
Total		50	70	70	70			260

SULFUR OXIDE CONTROL R&D AND RELATED PROGRAMS

Program VII FUEL AVAILABILITY SURVEYS	**Program Element** UNDESIGNATED FUEL AVAILABILITY	**Identification/Contract No.** NCAPC-VII-F

Initiation date FY 69	**Est. completion date** Indefinite	**1st decision review**	**2nd decision review**	**Initial contract amount**	**Estimated total costs** $1,750,000

Bureau responsible National Center for Air Pollution Control	**Sub organization**	**Project director** Dean High
Contractor or in-house organization performing work Various	**Location of work** Various	

Technical description

Conduct, sponsor, or support as yet unspecified projects for research and surveys on availability and location of low sulfur fuel and related factors of requirements, economics, and production, storage and transportation of these fuels. Not only will studies be made of known conventional reserves, but studies will also be made of tar sands, oil shale, new gas reserves created by nuclear explosion, secondary recovery methods, development of new low sulfur fuels from by-products and waste materials. Conduct analyses of results of exploration and discovery on the North American continent, off shore and other areas of the world of new fuel sources and types and the impact of these for SO_x pollution control.

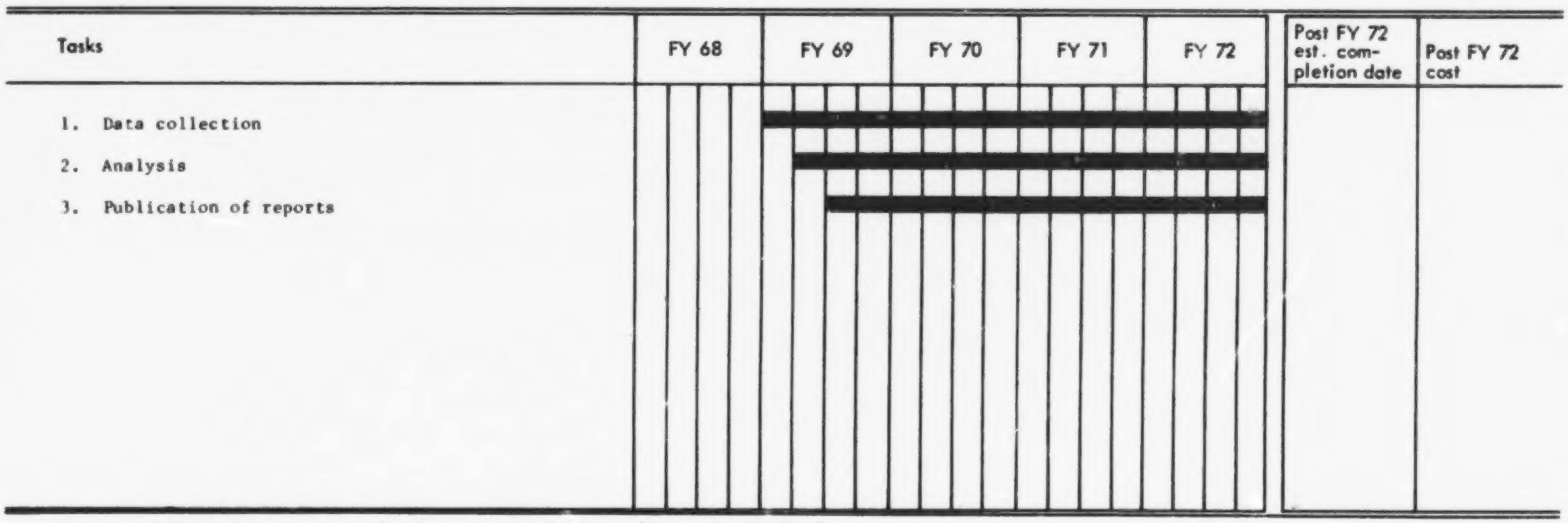
Utility/applicability

Develop factual basis for planning SO_x control programs and options.

Constraints to successful/on time completion

Other related or parallel R&D efforts

Specified studies on Availability of Low Sulfur Coal, Development of Special Purpose Coals, Availability of Natural Gas as a Substitute Low Sulfur Fuel, Technology and Availability of Liquified Natural Gas, Availability of Oil Studies.



Funding--Obligated & estimated obligations required for future (thousands of dollars)

Fund source(s)	Total prior years	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 cost	Total cost
● Agency NCAPC			350	350	350	350	350	1750
● Agency								
Total			350	350	350	350	350	1750
Program element performed by:								
● Agency NCAPC			350	350	350	350	350	1750
● Contractor								
● Other								
Total			350	350	350	350	350	1750

SUPPORTING INSTRUMENTATION DEVELOPMENT

I. Program VIII: Supporting Instrumentation Development

The SO_x control development program includes the development of sensing elements for SO_x pollutants and "feedback" devices for actuating process control devices. It also includes the development of instruments for measuring sulfur oxides in stack gases and in ambient air, including remote measurement from airborne survey platforms.

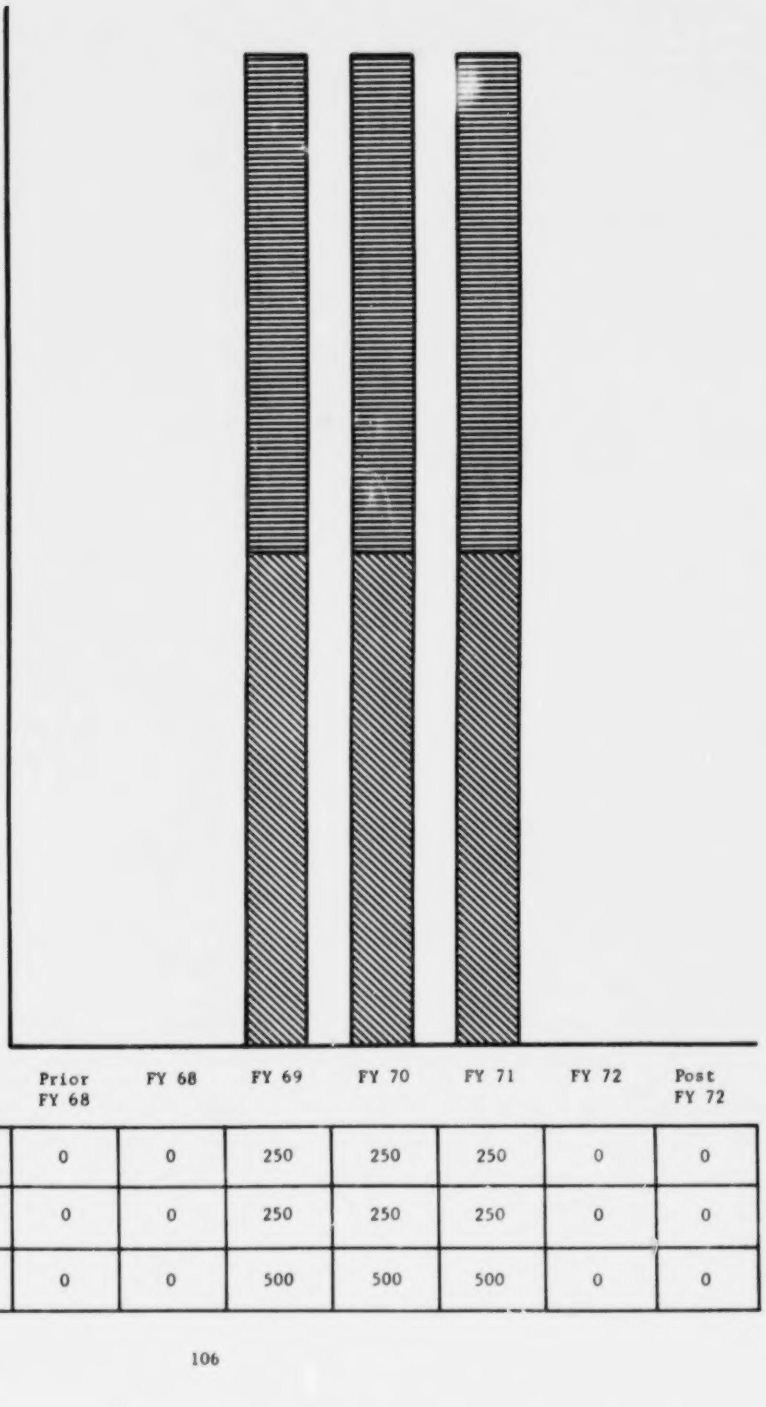
The NCAPC in the furtherance of the program will survey needs, and the off-the-shelf availability of this instrumentation. Based on the findings of these surveys, specifications for required instruments and devices will be established, and necessary research, design, development, and testing of hardware will be undertaken.

The total funding required for Program VIII, Supporting Instrumentation Development, is $1,500,000, all NCAPC funds. The distribution of this amount by program element and obligation fiscal year is shown in Figure 16. Following this summary is the detailed information on individual data sheets for each of the program elements which make up this program.

Figure 16

PROGRAM VIII. SUPPORTING INSTRUMENTATION DEVELOPMENT

By Program Element*
(Thousands of Dollars)



	Program Elements	Prior FY 68	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72	Total
▨	A. Development of Instrumentation for SO_x Control Activities	0	0	250	250	250	0	0	750
▤	B. Process Instrumentation and Control	0	0	250	250	250	0	0	750
	Total	0	0	500	500	500	0	0	1500

* All funds provided by NCAPC.

SULFUR OXIDE CONTROL R&D AND RELATED PROGRAMS

Program VIII SUPPORTING INSTRUMENTATION DEVELOPMENT		**Program Element** DEVELOPMENT OF INSTRUMENTATION FOR SO_x CONTROL ACTIVITIES			**Identification/Contract No.** NCAPC-VIII-A
Initiation date October 1968	**Est. completion date** June 1971	**1st decision review**	**2nd decision review**	**Initial contract amount** $ 250,000	**Estimated total costs** $750,000
Bureau responsible National Center for Air Pollution Control			**Sub organization** Chemical & Physical Development Section		**Project director** Altshuler
Contractor or in-house organization performing work Various			**Location of work** Various		

Technical description

The program is designed to provide instruments for measuring sulfur oxides in ambient air. Specific projects will be undertaken to develop remote stack monitors and airborne survey instruments, and improve ambient air monitoring instruments.

Utility/applicability

Instruments will permit the remote monitoring of processes to determine compliance with emission standards and will also permit the measurement of ambient air quality to evaluate the combined performance of controls in a region.

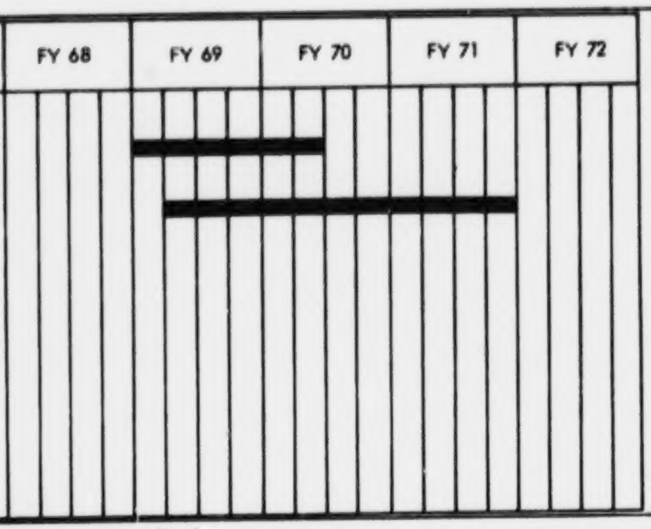
Constraints to successful/on time completion

Unexpected interferences in the ambient environment may disturb the expected precision in measuring sulfur oxides.

Other related or parallel R&D efforts

Tasks

1. Development of specifications for sulfur oxide ambient air monitoring instruments
2. Design, development, and test sulfur oxide monitoring instruments



Post FY 72 est. completion date	Post FY 72 cost

Funding--Obligated & estimated obligations required for future (thousands of dollars)

Fund source(s)	Total prior years	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 cost	Total cost
● Agency NCAPC			250	250	250			750
● Agency								
Total			250	250	250			750
Program element performed by:								
● Agency								
● Contractor Various			250	250	250			750
● Other								
Total			250	250	250			750

SULFUR OXIDE CONTROL R&D AND RELATED PROGRAMS

Program VIII SUPPORTING INSTRUMENTATION DEVELOPMENT	**Program Element** PROCESS INSTRUMENTATION AND CONTROL	**Identification/Contract No.** NCAPC-VIII-B

Initiation date September 1968	**Est. completion date** June 1971	**1st decision review**	**2nd decision review**	**Initial contract amount**	**Estimated total costs** $ 750,000

Bureau responsible NCAPC	**Sub organization** Various	**Project director** Various
Contractor or in-house organization performing work Various	**Location of work** Various	

Technical description

The program is designed to assure that process instrumentation and control is available for each air pollution control device which will find commercial application. Each instrument control system will require the development of: (1) elements for sensing the pollutant, (2) transducers to change the sensing pulse to a pneumatic or electrical pulse, (3) a recorder-controller, and (4) an actuated process control mechanism.

Utility/applicability

The program will assure that instrumentation exists for controlling various processes to establish emission standards.

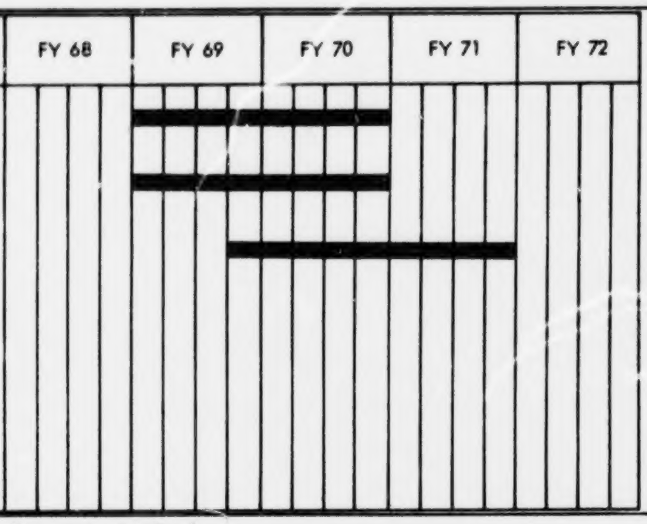
Constraints to successful/on time completion

"Off the shelf" sensing elements, transducers, recorder-controllers, and actuating mechanisms may not be available for the required integrated control system. Special development of any one of these steps may extend completion time.

Other related or parallel R&D efforts

Tasks

1. Survey of requirements for process control.
2. Survey of availability of "off the shelf" components.
3. Design and development of specific integrated control systems.



Post FY 72 est. completion date	Post FY 72 cost

Funding--Obligated & estimated obligations required for future (thousands of dollars)

Fund source(s)	Total prior years	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 cost	Total cost
● Agency NCAPC			250	250	250			750
● Agency								
Total			250	250	250			750
Program element performed by:								
● Agency								
● Contractors Various			250	250	250			750
● Other								
Total			250	250	250			750

PROGRAM DEVELOPMENT, ANALYSES AND EVALUATION

PROGRAM IX

J. Program IX: Program Development, Analysis, and Evaluation

In the planning, development, and management of its research programs, NCAPC requires not only certain in-house projects and supporting staff, but also the services of outside contractors and consultants. These services involve studies to assist in establishing objectives of SO_x R&D, identification of options, planning, multi-year programming, and revising plans and programs to reflect changes in the situation.

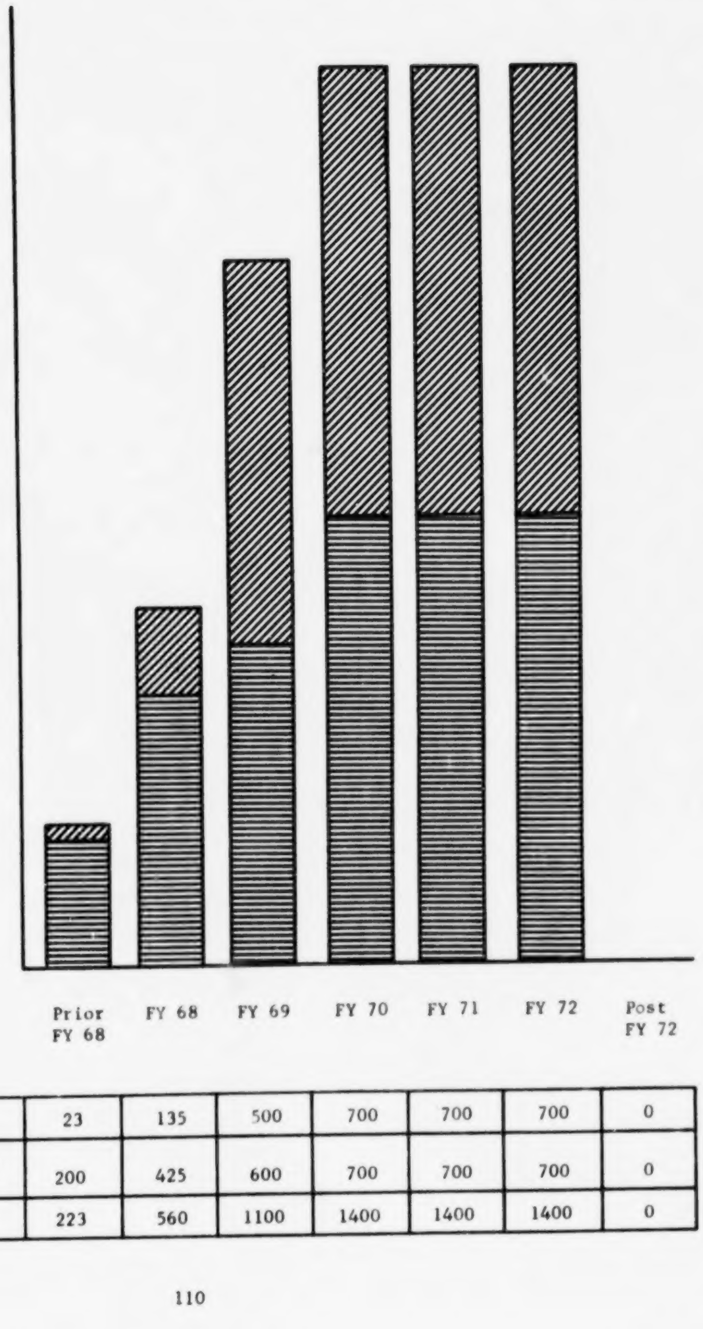
Consulting services may also include such items as cost-utility action models, and simulation of alternative control techniques for large new power plants. Contractual assistance may be used to supplement in-house personnel to develop systems for monitoring programs and study performance and coordinate governmentwide SO_x control R&D programs.

The total funding required for Program IX for the period through 1972 is $6,083,000. The distribution of this amount (all NCAPC funds) is shown by program element and fiscal year of obligation in Figure 17. Following this summary is the detailed information on individual data sheets for each program element which makes up this program.

Figure 17

PROGRAM IX. PROGRAM DEVELOPMENT, ANALYSES, AND EVALUATION

By Program Element*
(Thousands of Dollars)



	Program Elements	Prior FY 68	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72	Total
▨	A. General Planning Studies	23	135	500	700	700	700	0	2758
▤	B. Program Development, Implementation, and Control	200	425	600	700	700	700	0	3325
	Total	223	560	1100	1400	1400	1400	0	6083

* All funds provided by NCAPC.

SULFUR OXIDE CONTROL R&D AND RELATED PROGRAMS

Program IX PROGRAM DEVELOPMENT, ANALYSES, AND EVALUATION		**Program Element** GENERAL PLANNING STUDIES			**Identification/Contract No.** NCAPC-IX-A
Initiation date August 1966	**Est. completion date** June 1972	**1st decision review**	**2nd decision review**	**Initial contract amount** $23,000	**Estimated total costs** $2,758,000

Bureau responsible National Center for Air Pollution Control	**Sub organization** Various	**Project director** Various
Contractor or in-house organization performing work Various	**Location of work** Various	

Technical description

Studies to assist in decisions involving (1) basic objectives of sulfur oxide control, (2) identification of alternative courses of action, (3) strategic planning for control, (4) development of multiyear programs and financial plans, and (5) the continuous updating of plans.

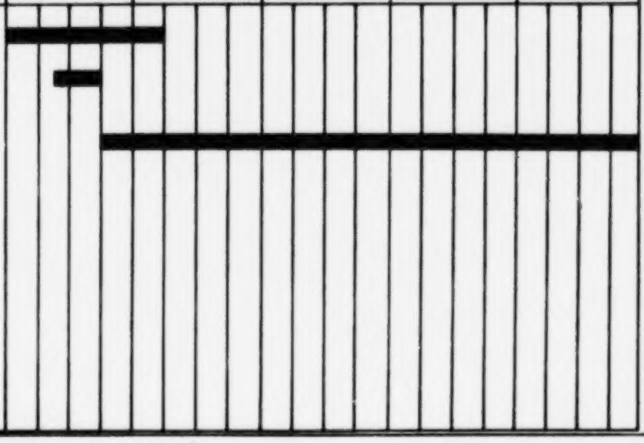
Utility/applicability

Results will provide program guidance and direction

Constraints to successful/on time completion

Other related or parallel R&D efforts

Tasks	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 est. completion date	Post FY 72 cost
1. Simulation approach to air pollution abatement							
2. Comprehensive program planning study for SO_x control							
3. Others							



Funding--Obligated & estimated obligations required for future (thousands of dollars)

Fund source(s)	Total prior years	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 cost	Total cost
● Agency NCAPC	23	135	500	700	700	700	0	2758
● Agency								
Total	23	135	500	700	700	700	0	2758
Program element performed by:								
● Agency NCAPC	0	75	500	700	700	700		2675
● Contractor Various	23	60	0	0	0	0		83
● Other								
Total	23	135	500	700	700	700		2758

SULFUR OXIDE CONTROL R&D AND RELATED PROGRAMS

Program IX PROGRAM DEVELOPMENT, ANALYSES, AND EVALUATION	**Program Element** PROGRAM DEVELOPMENT, IMPLEMENTATION, AND CONTROL	**Identification/Contract No.** NCAPC-IX-B

Initiation date July 1959	**Est. completion date** Continuous	**1st decision review**	**2nd decision review**	**Initial contract amount**	**Estimated total costs** $3,325,000

Bureau responsible National Center for Air Pollution Control	**Sub organization** Process Control & Engineering	**Project director** Paul Spaite
Contractor or in-house organization performing work Various	**Location of work** Cincinnati, Ohio	

Technical description

Develop inhouse contractual and consulting capabilities to identify, develop, and evaluate required studies, technical investigations and state-of-the-art surveys related to SO_x pollutant emission R&D; administer contracts; manage and monitor program and study performance in SO_x R&D; coordinate and control the Federal SO_x Control R&D Program.

Utility/applicability

A factually supported basis for an R&D program, and administrative and financial controls to display performance in R&D against program objectives and timetables.

Constraints to successful/on time completion

Availability of management data in structured and relatable form.

Other related or parallel R&D efforts

This program is a continuing effort which will provide for the overall management of R&D programs related to SO_x control.

Tasks	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 est. completion date	Post FY 72 cost
1. Program development	▬	▬	▬	▬	▬	Continuing	Unspecified
2. Implementation	▬	▬	▬	▬	▬	Continuing	Unspecified
3. Control	▬	▬	▬	▬	▬	Continuing	Unspecified

Funding--Obligated & estimated obligations required for future (thousands of dollars)

Fund source(s)	Total prior years	FY 68	FY 69	FY 70	FY 71	FY 72	Post FY 72 cost	Total cost
● Agency NCAPC	200	425	600	700	700	700		3325
● Agency								
Total	200	425	600	700	700	700		3325
Program element performed by:								
● Agency NCAPC	200	425	600	700	700	700		3325
● Contractor								
● Other								
Total	200	425	600	700	700	700		3325

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